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An international conference entitled "Arid Lands in a Changing World" sponsored by the American Association for the Advancement of Science Committee on Arid Lands and the University of Arizona, was held at Tucson in June, 1969. The Federal Water Quality Administration provided financial support for the conference and solicited papers to be presented in the Water Management and Salinity and Desalinization sessions. This report presents a selected group of the papers presented at those sessions which should benefit those concerned with water quality management problems in arid regions. The title of the papers included in this report are as follows: nitrate removal from agricultural wastewater; the effects of salinity standards on irrigated agriculture in the Colorado River basin; problems of pollution of irrigation waters in arid regions; water quality requirements and re-use of wastewater effluents; salinity control in return flow from irrigated areas--a demonstration project; water quality control problems in inland sinks; natural pollution in arid land waters; distillation of wastewaters: a water resource for arid regions; and animal waste runoff--a major water quality challenge. (WRSIC abstract) (Woodard-USGS)
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WATER QUALITY MANAGEMENT PROBLEMS IN ARID REGIONS

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FEDERAL WATER QUALITY ADMINISTRATION

DEPARTMENT OF THE INTERIOR

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FOREWORD

An international conference entitled "Arid Lands in a Changing World", sponsored by the American Association for the Advancement of Science Committee on Arid Lands and the University of Arizona, was held at Tucson in June, 1969.

The Federal Water Quality Administration provided financial support for the conference and solicited papers to be presented in the Water Management and Salinity and Desalinization sessions. This report presents a selected group of the papers presented at those sessions which will benefit those concerned with water quality management problems in arid regions.

The editors wish to acknowledge the cooperation they received from the authors in the completion of this task.

James P. Law, Jr.
Jack L. Witherow

Ada, Oklahoma
October, 1970

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NITRATE REMOVAL FROM AGRICULTURAL WASTEWATER

by

Percy P. St. Amant and Louis A. Beck [1]

The San Joaquin Valley of California is the largest single agricultural area in the State. The nearly eight million acres (3.24×10^6 ha) of irrigable land of this Valley is one of the richest agricultural areas in the world. Massive water import facilities have recently been constructed to assure that sufficient water is available for irrigation. Now that water is available much of the irrigable land is being developed for crop production. However, as often happens, the solving of one problem develops another. This problem is how to dispose of the saline agricultural wastewaters that result from irrigated agriculture. The U. S. Bureau of Reclamation has begun construction of the San Luis Drain to transport these wastewaters from Kettleman City on the south to the western edge of the Sacramento-San Joaquin Delta near Antioch. The State is continuing studies with the aim of constructing a drain at a later date to provide drainage for the rest of the Valley.

In 1965, the Federal Water Pollution Control Administration (FWPCA) began an investigation of the effects of the proposed San Joaquin Master Drain upon the quality of receiving waters. (The San Joaquin Master Drain considered both the Federal and State drainage facilities.) In 1967, the FWPCA report "San Joaquin Master Drain Effects on Water Quality of San Francisco Bay and Delta" indicated that serious pollution problems would likely result if the wastewaters were discharged into the Bay System. Nitrogen, primarily in the nitrate form, is the most serious potential pollutant. This report also recommended that no wastewater be emptied into the Bay System until a suitable method for nitrate removal has been developed and that studies be vigorously pursued during 1967, 1968, and 1969 to firmly establish the economic feasibility of nitrogen removal treatment of San Joaquin Valley agricultural wastewaters.

In January 1967, representatives of the U. S. Bureau of Reclamation (USBR), the FWPCA, and the California Department of Water Resources (DWR), met to discuss the findings of the FWPCA's report. It was at this time that the Interagency Agricultural Waste Water Treatment Center was established. The objective of the Center was to determine an economically feasible method of removing nitrogen from the agricultural wastewaters of the San Joaquin Valley. The estimated Summer peak wastewater flow into the Bay System after the year 2000 will be about 700 million gallons per day (2.65×10^6 cu m/day). The estimated constituent concentrations in San Joaquin Valley agricultural wastewaters is shown in Table 1.

---

[1] Project Director, San Joaquin Project, Federal Water Pollution Control Administration; and Chief, Quality and Treatment Unit, California Dept. of Water Resources, Fresno.

TABLE 1

ESTIMATED CONSTITUENT CONCENTRATIONS IN SAN JOAQUIN VALLEY AGRICULTURAL WASTEWATERS

Chemical Constituents	Concentrations in mg/l	
Minerals	Initial	After 50 yrs of Operation
Calcium	220	160
Magnesium	160	90
Sodium	1,900	540
Potassium	20	10
Carbonate	0	0
Bicarbonate	220	200
Sulfate	3,500	740
Chloride	1,000	670
Nitrate	90	90
Boron	11	3
Total Dissolved Solids	6,800	2,500

Non-Time Varying Constituents	Concentrations in mg/l
Nutrients	
Total Nitrogen	21
Total + Organic Phosphate	0.35
Pesticides	<0.001
Others	
Dissolved Oxygen	5-10
5 Day B.O.D.	1-3
C.O.D.	10-20
Sufactant (ABS)	0.0
Phenolic Material	0.001
Grease and Oil	0.5

Prior to 1967, the California Department of Water Resources had made arrangements to utilize U. S. Bureau of Reclamation land along the Delta-Mendota Canal near Firebaugh, California, for construction of pilot-scale algae stripping facilities. With the start of the Interagency study, this area was expanded to include space for desalination and bacterial denitrification studies. The organization at the Firebaugh Treatment Center is quite unique (Figure 1). The most unique feature of the Center is the intermingling of personnel. The Center is guided by a committee consisting of a project director from the DWR and the FWPCA and a designated representative from the USBR. This committee is assisted by a Board of Consultants comprised of Drs. Oswald, Golueke, and McCarty. Essentially, the work at the Center is providing each of the three agencies with more information at a lesser cost than would have been possible with three separate single-agency studies.

Methods of nitrate removal being studied at the Center include algae stripping and bacterial denitrification. Two methods of bacterial denitrification are being evaluated: pond denitrification and filter denitrification. Desalination is also being evaluated.

Desalination

The FWPCA, through an agreement with the Office of Saline Water (OSW), is evaluating two methods of desalination of agricultural wastewaters--reverse osmosis and electrodialysis. The reverse osmosis unit evaluated was operated at a pressure of 750 psi (52.7 kg/sq cm) using a cellulose acetate membrane. With this unit up to 93 percent ion removal was experienced using 6,000 mg/l wastewater. In the electrodialysis unit tested, about 30 percent of the ions were removed each time the wastewater was passed through the membrane stack. Of the two units evaluated, neither unit significantly removed the boron ion. The reverse osmosis unit removed about 20 percent of the nitrate ions, while the electrodialysis unit removed about the same percentage as it did the other ions.

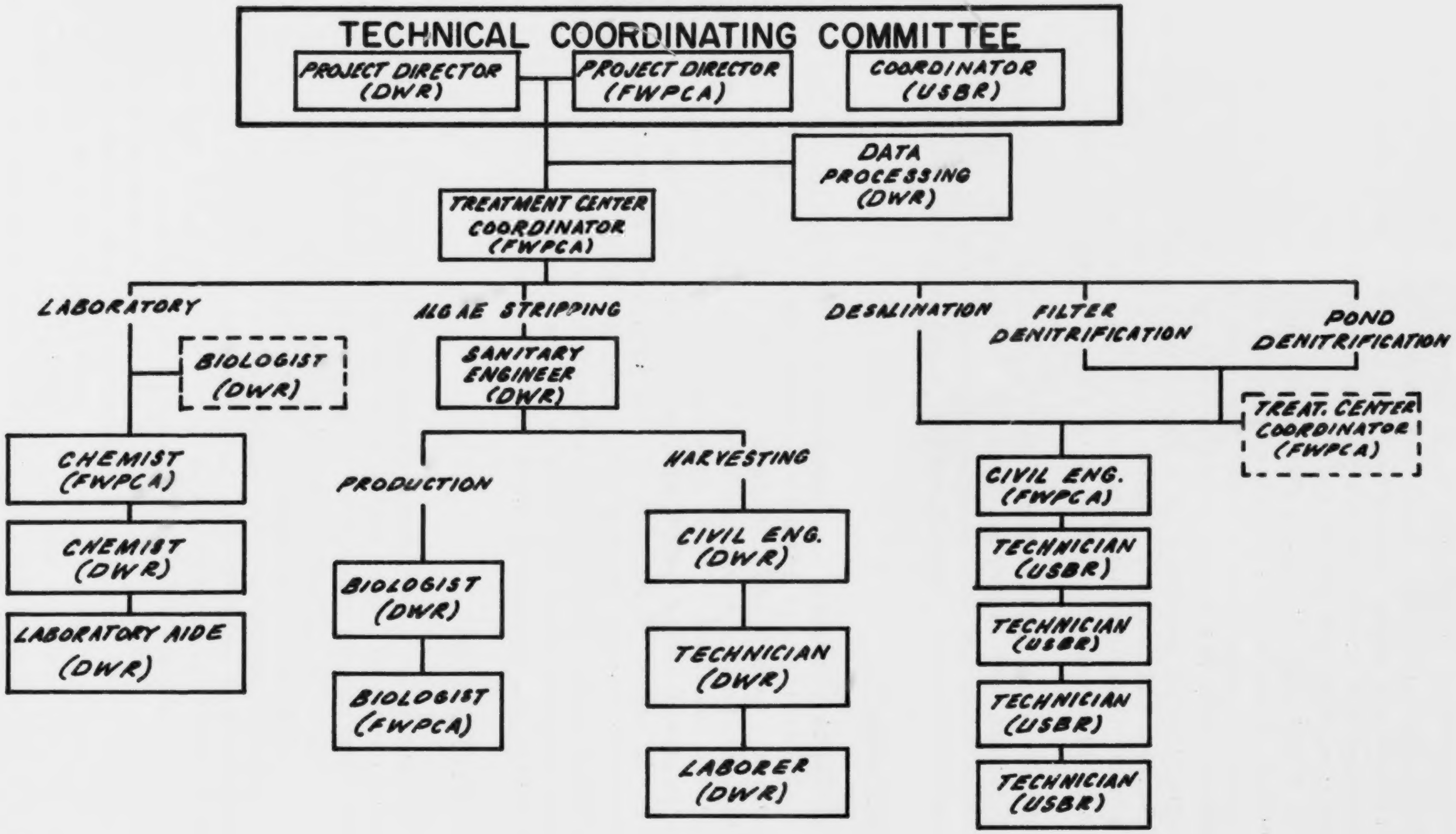
Algae Stripping

The basic theory of algae stripping to remove nitrogen is quite simple--grow a crop of algae which ties up the nitrogen in their cell structure and then remove the algae from the water. However, it is not as simple as it sounds. While algae will grow quite easily in this water, the dense crop of algae required to remove 90 percent of the nitrate-nitrogen is another problem. Our studies at Firebaugh have indicated that the agricultural wastewaters lack both phosphate and iron in the amounts required to grow this dense crop of algae. We have tied up 90 percent of the nitrogen in the algal cell structure with the addition of phosphate and iron. Algal nutrition studies were conducted in flasks at the Center. The effect of individual growth parameters (nutrients, depth, detention time, mixing, etc.) were studied in small growth units. The results of the experiments in the small growth units were combined to determine the operating conditions for the quarter acre growth pond. The results from this large growth pond were then scaled up to prototype size.

FIGURE 1-ORGANIZATION CHART

AGRICULTURAL WASTE WATER TREATMENT CENTER

FIREBAUGH


TECHNICAL COORDINATING COMMITTEE
PROJECT DIRECTOR (DWR)
PROJECT DIRECTOR (FWPCA)
COORDINATOR (USBR)
DATA PROCESSING (DWR)
TREATMENT CENTER COORDINATOR (FWPCA)
LABORATORY
BIOLOGIST (DWR)
CHEMIST (FWPCA)
CHEMIST (DWR)
LABORATORY AIDE (DWR)
ALGAE STRIPPING
SANITARY ENGINEER (DWR)
PRODUCTION
BIOLOGIST (DWR)
BIOLOGIST (FWPCA)
HARVESTING
CIVIL ENG. (DWR)
TECHNICIAN (DWR)
LABORER (DWR)
DESALINATION
FILTER DENITRIFICATION
POND DENITRIFICATION
TREAT. CENTER COORDINATOR (FWPCA)
CIVIL ENG. (FWPCA)
TECHNICIAN (USBR)
TECHNICIAN (USBR)
TECHNICIAN (USBR)
TECHNICIAN (USBR)

The removal of the algae from the water is an even more difficult problem than growing a dense crop of algae. Methods which will be investigated at Firebaugh for algae removal include centrifuging and micro-screening. The most promising method, however, is flocculation and either sedimentation or flotation. We have been able to achieve over 95 percent removal of algal cells by flocculation and sedimentation using either alum, lime or polyelectrolytes--all at approximately the same cost. After we have concentrated the algae by either sedimentation or flotation, it must be dewatered. This summer we will be operating pilot-scale units to test dewatering by centrifugation and vacuum filtration.

The disposal of the algae may pay part of the cost of treatment. Several concerns have expressed interest in the use of algae for such things as animal feed, soil conditioner, or for production of adhesives. In livestock feed, algae would replace the fish meal or protein supplement and have a value of approximately $150 a ton ($165/metric ton). Poultry raisers are also interested in using algae for feed. Besides the protein, algae contains xanthopyll, which adds color to the flesh of the bird and to the egg yoke and increases the market value. The company interested in using algae as a soil conditioner predicts that algae may be used by the home gardener similar to the use of Milorganite (condition the soil as well as having some fertilizer value.) Algae would have a value of about $100 a ton ($110/metric ton) as a soil conditioner. A value of about $120 a ton ($132/metric ton) could be realized by utilizing algae in the production of adhesives. If none of these methods of disposal are practiced, it may be necessary to dispose of algae by digestion. The methane gas produced could be used to provide power required for the treatment process. Laboratory experiments by Dr. Oswald indicate that the methane produced by digestion would produce more power than required in the treatment process.

Bacterial Denitrification

Bacterial denitrification is accomplished through the use of microorganisms which, in the absence of dissolved oxygen, oxidize organic material and reduce the nitrate-nitrogen to nitrogen gas. A wide variety of common facultative bacteria have the ability to bring about denitrification. Denitrification of nitrates is a two-step process in which the nitrates are reduced to nitrites and then to nitrogen gas. This method poses no by-product waste disposal problem. However, the organisms can only achieve denitrification if they are supplied with an organic energy source. Since the agricultural wastewaters are very low in organic materials, it is necessary to add an organic source to the water. At the Firebaugh Treatment Center methanol is added to the wastewater to supply this required organic source. We are actively evaluating two methods of bacterial denitrification at the Firebaugh Center: pond denitrification and filter denitrification.

Pond Denitrification

Relatively deep ponds are used in this process to develop the required anaerobic conditions. After methanol addition, the wastewater enters near the bottom of the pond at a detention time of 5-20 days and the nitrogen-free water is discharged at the top of the pond. The denitrifying organisms are free-floating in the pond with the more dense concentration near the bottom.

This denitrification method was initially proposed by Dr. Perry L. McCarty. In order to determine if this process would work under field conditions, 3-ft. (0.91 m) diameter pipes, 6 to 11 feet deep (1.83 m to 3.35 m) were installed to simulate deep ponds. The simulated ponds demonstrated that this process of denitrification would work under field conditions. Based on these results, two deep ponds were constructed at the Center. One pond is 60 feet (18.3 m) by 200 feet (61.0 m); the other 50 feet square (15.2 m). Both ponds are approximately 14 feet deep (4.28 m). The larger pond is covered with a floating styrofoam material to reduce algal growth and surface reaeration.

In August 1968, pilot-scale studies began using these two ponds. A nitrate-nitrogen removal of 90 percent has been achieved in the larger pond at a ten day detention time. The smaller pond has experienced hydraulic short-circuiting, thus reducing the nitrogen removal efficiency. These problems have now been corrected and the pond is now operating. Preliminary data this winter indicate that an increase in the detention time may be necessary as the water temperature drops.

Filter Denitrification

This method is very similar to the deep pond process except an aggregate bed is used. An advantage of this method over the pond system is that the surface area to which the organisms can attach themselves is greatly increased, thus producing a greater concentration of bacteria. Also since the bacteria have something to which they can attach themselves, the wastewater can be passed by the bacteria at a higher velocity without washing them out as would happen in a deep pond where the bacteria are "free-floating." Because of these advantages, the nitrate-nitrogen is reduced to nitrogen gas more quickly than in deep ponds.

All filter denitrification studies at the Firebaugh Center have been performed in upflow columns with a 6-ft. (1.83 m) media depth. Methanol is added to the wastewater just before it enters the bottom of the filter. Initial filter studies were accomplished using 4-inch (10.2 cm) diameter pipes. These small pipes demonstrated that this process would work well under field conditions. Based on these results 18-inch (45.7 cm) and 36-inch (91.4 cm) diameter filters were installed.

The major variables investigated have been detention time and filter media. Some of the various media evaluated include sand, activated carbon, gravel, volcanic cinders, coal and a commercially produced trickling filter media. The most satisfactory media has been one-inch (2.54 cm) diameter gravel. Smaller diameter media were investigated but after several months of operation the head loss through the filters was greater than experienced in the one-inch (2.54 cm) diameter media. The majority of the head loss through the filter is caused by the dense bacterial mass within the filter. As the bacterial mass builds up and the head loss increases, short-circuiting will begin to occur within the filter thus reducing the nitrogen removal efficiency. Some of the filters have been operating continuously for nearly a year without requiring cleaning due to bacterial build-up. The head loss through these filters has not significantly increased during this continuous period of operation.

The detention times evaluated have been two hours, one hour, and one-half hour. All filters have a minimum of quarter point sample ports so nitrogen removal profiles can be studied. At all detention times studied greater than 90 percent removal of the 20 milligrams per liter (mg/1) of nitrate-nitrogen has been achieved. However, during periods when the influent wastewater is below 10°C, the removal efficiency of the filters is reduced. Studies are presently underway to try to better define the temperature effect on the bacterial denitrification system. From data collected thus far, it appears that a filter using one-inch (2.54 cm) diameter aggregate at a one-hour detention time will be effective in removing 90 percent of the 20 mg/1 of influent nitrate-nitrogen at temperatures above 12°C.

A larger filter, 10 feet (3.0 m) square, has recently been constructed at the Center. This filter, filled with one-inch (2.54 cm) diameter aggregate, will be used to evaluate hydraulic characteristics of large upflow filters.

Comparison of Biological Denitrification Methods

As mentioned earlier, estimated flows from the San Joaquin Valley will approach 700 million gallons per day (2.65×10^6 cu m/day) after the year 2000.

The land requirements for the three denitrification methods will vary greatly, based on present knowledge. The algae stripping method will require about 9,000 acres (3645 ha) of land, pond denitrification about 1,100 acres (445 ha) and filter denitrification about 150 acres (60.8 ha).

At 700 mgd (2.65×10^6 cu m/day) the algae stripping method will produce approximately 450 tons (410 metric tons) per day of dried algae. The bacterial denitrification systems produce no usable by-product.

Initial estimates project the costs of these three biological systems nearly the same--around $10 per acre foot ($8.10/1000 cu m), or $25 to $30 per million gallons ($6.60 to $7.90 per million 1). Recent reduction in the cost of methanol may further reduce the cost of bacterial denitrification. Also the original cost for the algae stripping method did not include any return for the dried algae which may also reduce the cost of this system.

The California Department of Water Resources cost estimates for the formerly planned Master Drain are about $110 million for Western Delta Area discharge, and about $250 million for direct ocean disposal. At a treatment cost of $10 per acre foot ($8.10/1000 cu m) the capitalized cost of conveyance, treatment, and discharge into the Western Delta is about two-thirds the cost of direct ocean disposal.

Our objective at the Interagency Agricultural Waste Water Treatment Center is to develop an economically feasible method of removing the nitrogen from the agricultural wastewaters of the Valley. In order that construction of the wastewater disposal drain can continue as scheduled, we must have the answer by January 1970. We are actively refining the nitrogen removal systems so accurate economic evaluation can be made by that date.

THE EFFECTS OF SALINITY STANDARDS ON IRRIGATED AGRICULTURE IN THE COLORADO RIVER BASIN

by

Gary N. Dietrich and L. Russell Freeman [1]

The Federal Water Pollution Control Act, as amended, authorizes the establishment of water quality standards for interstate waters. These standards are to provide for the preservation and enhancement of water quality and the protection of present and potential water uses. The Act gives the States the opportunity to develop and adopt the standards and submit them to the Secretary of the Interior for his approval and adoption as Federal standards. Where he finds the State standards unacceptable, the Secretary is empowered to promulgate Federal standards. State enforcement of standards is encouraged; however, Federal enforcement is possible. All but one of the States, the District of Columbia, Puerto Rico, the Virgin Islands and Guam have adopted standards, and these have been fully or partially approved as Federal standards.

This paper discusses salinity criteria for the Colorado River Basin. Although salinity criteria ordinarily would be included in the water quality standards, the seven States of the Colorado River Basin concluded, after careful consideration, that sufficient information was not available to develop and implement such criteria. The Secretary of the Interior concurred in this decision and further determined that studies should be undertaken to develop the basis for formulating equitable, workable and enforceable salinity criteria. Consequently, the water quality standards adopted and approved for the Colorado River and the other interstate waters of the Basin are void of mineral quality criteria, or salinity criteria as they are commonly called. The task of formulating such criteria has been deferred pending the development of the capacity and knowledge to perform this task.

Salinity criteria present some significant and even serious implications for irrigated agriculture, hence the reason for selecting this topic for discussion. It is to be noted that other aspects of water quality standards -- sediment and turbidity criteria and nutrient, pesticide and even temperature criteria -- also apply to and affect irrigated agriculture. However, to enable an adequate treatment of the salinity criteria issue, a discussion of these other aspects is not included in this paper.

Salinity is the most serious water quality problem in the Colorado River Basin. Like many streams in the arid West, the Colorado River displays a progressive increase in salinity between its headwaters and mouth.

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[1] Respectively, at the time of presentation, Deputy Director, Division of Technical Support and Deputy Director, Colorado River-Bonneville Basins Office, Federal Water Pollution Control Administration.

Currently, the average salinity concentrations in the Lower Colorado River range from approximately 750 mg/l at Hoover Dam to about 850 mg/l at Imperial Dam. Approximately 47 percent of these concentrations derive from natural causes -- mineral springs and diffused pick-up of salts by surface drainage -- and the remainder results from man's development and use of the Basin's water resources. Planned and proposed development of the water resources will further increase the existing levels of salinity, and, by the year 2010, average salinity concentrations are expected to be 990 mg/l at Hoover Dam and 1220 mg/l at Imperial Dam.

Generally, as salinity concentrations increase above 500 mg/l, the value of water begins to diminish and the costs associated with its use begin to increase. Increasing costs are incurred in water softening or alternately, in the form of costs of corrosion, fabric wear and increased use of detergents. They also include diminished crop yields, the inability to grow certain high-value crops and the need for greater amounts of leaching water to maintain salt balance in the root zone. Because of such costs, increasing salinity levels in the Lower Colorado River constitute a significant water quality problem. In fact, the economic costs presently suffered by the water users of the lower Colorado River amount to several millions of dollars annually, and these will increase to over 15 million dollars per year by 2010 if the predictions of future increases in salinity hold true.

The problem faced in water quality management in the Colorado River Basin is one of improving existing mineral quality, or at least, minimizing future salinity increases, particularly in the Lower Colorado River where the effects of degraded mineral quality are most severe and most costly. On first examination, salinity criteria appear ideally suited for meeting either of these purposes. Such criteria would provide concentration limits for total amount of salt and its constituents at each of some dozen or two dozen points throughout the river system and would set forth a plan of implementation and enforcement delineating how and where sources of man-caused salinity would be controlled to achieve compliance with these limits. Unfortunately, neither the development nor the implementation of such criteria would be simple. In fact, these criteria could significantly interfere with the development and consumptive use of water for irrigated agriculture and other purposes.

The confounding problem in developing salinity criteria for the Colorado River Basin, where irrigation is the principal source of man-caused salinity, results from the consumptive use of water in crop production. From 50 to 70 percent of the water applied in irrigation is consumed by evapotranspiration. The remaining 30 to 50 percent returns to the river system as irrigation return flow. This return flow usually contains all of the salt load of the applied water, but in a smaller volume of water. It may also pick up additional salts in the process of returning to the stream. Accordingly, as water passes through an irrigation cycle, its salinity concentrations are increased. Even if there were no salt pick-up by irrigation return drainage and no non-beneficial evaporative losses of water, irrigation would unavoidably increase salinity. To avoid this salinity increase would require nothing less than a reduction of consumptive use, presuming that there exists no economically feasible means of removing salts from irrigation return flow. Such implementation of salinity criteria would severely conflict with existing water rights, interstate compacts and international agreements which have established the division and allocation of the Basin's water resources. Two examples will serve to illustrate this conflict.

Suppose that salinity criteria based on existing salinity levels were to be set at several points along the lengths of the Colorado River and its major tributaries. Unless the River's salt load could be reduced markedly, compliance with these criteria would lock-in present patterns of water use by precluding any additional consumptive use of the Basin's waters. Future development of irrigated lands, as now planned and proposed, would have to be halted and full use of the waters allocated by compact to the Upper Basin States would have to be sacrificed. In effect, these criteria would abrogate undeveloped water rights and thereby would impose restrictions not commonly supposed to be the function of water quality standards.

On the other hand, it would be possible to establish salinity criteria throughout the Basin which would be based on existing salinity concentrations plus allowances for future increases of salinity expected to result from future consumptive use. However inviting this possibility might seem, it must be noted that these criteria would fix the distribution of future consumptive uses and thereby would predetermine the future development of irrigation and other water uses. Accordingly, the setting of these criteria would be impractical to the degree that future water use cannot or should not be predetermined. Furthermore, it is far from certain that such criteria can be established without imposing inequities, even though their principal objective would be the achievement of an equitable pattern of consumptive uses compatible with prevailing water rights and compact divisions of water. The principal deficiency of these criteria, however, would be their failing to protect and preserve present water quality. This would be of greatest concern to current water users of the Lower Colorado River who would suffer significant degradation of their water supply because of the built-in allowances for future increase in salinity.

These difficulties in developing salinity criteria do not mean that such criteria cannot be derived or are inappropriate for controlling mineral quality. It is technically possible to develop basin-wide salinity criteria for the Colorado River Basin. Sufficient data on historical stream flows and mineral quality, on flow-quality relationships and on expected stream flows and quality under various levels of planned or proposed water resource development are available for this purpose. Accordingly, salinity criteria to preserve existing mineral quality with or without allowances for various patterns of future development can be formulated. The problem is not so much in this initial step of establishing criteria, except for the difficulties in formulating equitable criteria, as in the subsequent step of implementing the criteria. With respect to the appropriateness of salinity criteria, it must be recognized that their purpose is the protection of legitimate water uses, including irrigation uses. That the protection of existing water uses in the Lower Basin requires a restriction of upstream water uses is less a fault of these criteria than the limitations of nature. If public policy is to preserve presently developed water uses, this might require some restriction of new water uses, regardless of whether salinity criteria or other regulatory devices are employed to effect this policy. In this sense, salinity criteria are nothing but tools to implement public policy and on this point an examination of how such criteria could be administered and what implications they would have for irrigated agriculture is in order.

Although there are a number of alternative measures which are discussed later, there are only two direct approaches to implementing salinity criteria within the Colorado River Basin: the regulation of consumptive water uses and the desalination of waters whose salinity has been concentrated by consumptive use. To implement salinity criteria through the regulation of consumptive uses would require adding quality to quantity in determining water rights and interstate divisions of water. The essential feature of this approach would be the reservation of portions of river flows for the carriage of salt loads. This water would remain in the river system and would not be allocated to consumptive use. River flows in excess of salt carrying flows would be available for division among the States and allocation to water users. It is immediately apparent that such an approach would require considerable modification of the institutional devices and procedures currently employed to administer western water laws. Even so, these modifications would be insignificant compared with the changes that would have to be made in perfected water rights and interstate divisions of water. In most cases, salinity criteria would restrict rights to consumptive water use much more severely than existing water rights which are wholly based on a division of available quantities of water. The following example will illustrate this point.

At Hoover Dam, the Colorado River presently carries an average of 10.9 million tons of salt per year. If a salinity criterion of 800 mg/l total dissolved solids were to be set at the Dam, an average annual flow of about 10 million acre-feet would be required to carry this salt load. Present average annual flows at Hoover Dam are about 11 million acre-feet. Consequently, a salinity criterion of 800 mg/l would permit only 1 million acre-feet per year of additional upstream consumptive use. This would deprive the Upper Basin of a substantial part of its average annual allocation of 7.5 million acre-feet, as provided by the Colorado River Compact, and would necessitate considerable readjustment of prevailing interstate divisions of water and of existing water rights within the Basin States. At the present time, for the reasons illustrated in the foregoing example, the employment of consumptive use restrictions to implement salinity criteria does not appear promising. Nevertheless, eventual and perhaps partial use of such restrictions can and should be foreseen, whether these are specifically for the purpose of implementing salinity criteria or are incidental to other means of managing the Basin's water resource. A case in point is the following. If it is assumed that 3000 mg/l total dissolved solids is the practical limit for usable water and that the last user on the Colorado River is to enjoy water quality not exceeding this limit, then to carry the River's 10.9 million tons per year salt load at this last point of use will require an annual average river flow of about 2.4 million acre-feet. This would be water reserved from upstream consumptive use for allocation to salt carriage and, in a sense, for wasting into the ocean or into the Salton Sea. As this demonstrates, it is virtually impossible to use the entire water resource of the Basin for consumptive use if the last users are to enjoy any reasonable levels of mineral quality. Consequently, restrictions on consumptive use for the reservation of salt carrying flows are a practical necessity.

The other direct approach to implementing salinity criteria would involve the desalting of wastes from consumptive use operations, including irrigated agriculture. A percentage of the salt proportional to the percentage of the water consumptively used would be removed so that the water returned to the river system would have the same salinity concentration as that withdrawn. Such an approach, if perfected, would permit consumptive use of nearly all of the water resource (some water would be lost in brine disposal) and would eliminate the need to allocate large river flows for carriage of salt load. Furthermore, this approach would put salinity control on the same basis as the control of other pollutants, by requiring the removal of salts as necessary to compensate for loss of water in the water-use cycle. Unfortunately, this desalting approach is presently encumbered by some severe economic and technical constraints. Foremost among these is the high cost of desalting water. Several recent studies conclude that large-scale desalting, usually combined with thermal power generation, for the production of waters for direct use will be economically feasible in the near future (1980 to 2000). However, the approach just described would require small-to-medium scale desalting plants for waste water treatment, and it is doubtful that such small scale plants will be economically feasible in the near future. The technical problems include the necessity of disposing of brines (these cannot be reintroduced into the river system and must be disposed of in closed basins, deep geological formations or the ocean) and the necessity of providing drainage systems for all irrigated lands in order to collect return flows for treatment. Notwithstanding these several liabilities, the desalting approach may hold some promise for the future.

Recognizing the problems in formulating and implementing salinity criteria, it seems appropriate to turn attention to other approaches to salinity contol -- approaches which do not necessarily depend on the establishment of criteria. Currently, there appears to be three such approaches: the abatement of salinity at selected sources including natural sources, the augmentation of river flows and the desalination of waters for use. Measures to abate salinity at selected sources would seek to control salinity arising from causes other than beneficial consumptive use. About 47 percent of the current levels of salinity at Hoover Dam derive from natural causes -- the dissolution of the salts in soils and geologic formations by natural surface and subsurface flows. In some cases, these causes of salt loading can be controlled by such methods as the plugging or suppression of mineral springs; the diversion of stream flows around salt domes and other areas of substantial salt pick-up; and the diversion of highly mineralized surface flows into closed areas where they can be disposed of or used for salt-tolerant uses. These several measures would eliminate a part of the salt load presently reaching the Colorado River and thereby would permanently reduce salinity concentrations in the River.

Another important cause of salinity is the salt pick-up by irrigation return flow as it percolates through the soils enroute from the irrigated land to the river system. This salt pickup accounts for about 26 percent of the salinity presently measured at Hoover Dam. This salt load can be significantly reduced by (1) eliminating excess drainage (over and above that required for leaching in maintaining salt balance in the root zone); (2) the lining of canals and other conveyance channels; (3) intercepting drainage at the bottom of the root zone and conveying it to the river system, thus short-stopping unnecessary subsurface travel and (4) selecting for new irrigation only those lands which are underlain by low salinity soils. These measures would reduce man's contribution of salt input into the river system and thereby would serve to permanently reduce salinity. Preliminary estimates indicate that a program of selected salinity source control can achieve salinity reductions of up to 300 mg/1 at Hoover Dam. Such a program would depend, in large measure, on irrigated agriculture. The provision of structural control measures such as drains and canal lining and the institution of improved water management practices would be necessary to the full success of the program. Studies indicate, considering the potential multiple benefits of such features, that there is ample economic justification for the development of such measures.

Augmentation of Colorado River flows would involve interbasin importation of water, weather modification, water salvage or a combination of these measures. Although these means are currently being proposed (and studied except for interbasin importation) for the primary purpose of meeting expected future water shortages, they would provide significant water quality benefits. For example, 2.5 million acre-feet per year of 300 mg/1 water delivered at Hoover Dam would reduce present levels of salinity by about 75 mg/1. Consequently, flow augmentation is also an attractive means for improving the mineral quality of the Colorado River.

Finally, the desalting of water for direct use is an approach that may be necessary to mitigate the consequences of uncontrolled or only partially controlled salinity; that is, for providing acceptable water supplies to replace those that are over mineralized. In addition, of course, desalting also can serve to extend the Basin's water supply.

Large-scale desalting combined with electric power generation is being studied. Preliminary results indicate that this means of producing high quality water may be economically feasible in the foreseeable future (1980 to 2000). Certainly, desalting is a potential alternative to be considered in solving the salinity problem of the Colorado River Basin.

In conclusion, it is foreseen that the establishment of salinity criteria for the Colorado River Basin will be difficult and may be a long time in coming. A promising alternate and interim approach would be the study and implementation of the three means of control just described. The abatement of the increasing salinity of the Colorado River system cannot afford further deferral particularly when the techniques to achieve such abatement seem close at hand. A combination of salinity-source abatement, flow augmentation and desalination can accomplish immediate and needed results. And, if and when salinity criteria can be and are established, these measurers can be easily and readily factored into whatever devices are developed to implement and enforce these criteria.

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PROBLEMS OF POLLUTION OF IRRIGATION WATERS IN ARID REGIONS

by

H. B. Peterson, A. A. Bishop, and J. P. Law, Jr. [1]

Historically, the users of irrigation water have been more concerned with quantity rather than the quality being used. Now they must also be concerned with the quality of water being used as well as that which returns to the supply to be reused for other purposes or for irrigation. We no longer have enough water to pollute and discard.

A hydrologic unit (river system with its drainage area and groundwater basin, etc., and with its animal, plants, minerals, and people) can be considered as a self-contained, hydro-pollution-purifying system. The state of the system without man in it, if we can imagine such, is natural and produces changes as a result of the dynamism within it. In this natural or pristine state, changes in climate, vegetation, geologic erosion, animal inhabitants, etc., are dynamic, having an impact on the quality of the environment and resulting pollution in the natural drainage from the area. The introduction of man into the system with his power to create major changes and to introduce new or additional pollution or treatment vectors in the waters of the system make it imperative that the system be considered in its entirety and not from the standpoint of a single use or source of pollution. Man superimposes on the system, cities, transportation facilities, agriculture, irrigation and drainage facilities, manufacturing plants, mining, timber harvesting, range use, recreation, and other changes too numerous to mention. The interactions of man, and the changes he produces, within the hydrologic system is the major concern of this paper, particularly with respect to irrigation and irrigation return flow.

Those who live in arid regions are intensely aware of the keen competition for a limited water supply. The climate is conducive to high evapotranspiration losses and a minimum of natural leaching. For intensive crop production, irrigation is necessary in arid regions while it is used only to supplement rainfall in more humid areas. Water quality requirements for agriculture vary considerably with soils, crops, and climate. The adverse effects of low quality on soils and plant growth are related to the frequency and amount of water applied. Problems associated with deteriorating water quality are, therefore, more numerous and acute in arid and semiarid areas where the water requirements of the growing crop are satisfied almost entirely by irrigation.

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Sources and Types of Pollution Affecting Water Quality

In the hydrologic cycle, it is natural for the pollution of a river system to increase as the water moves toward the ocean where it is purified by distillation and returned to the watershed. Enroute, considerable purification takes place in the streams by oxidation and biological degradation. Pollutants come from many sources before, during, and after irrigation. They come from the animals; soils, both irrigated and non-irrigated; fertilizers; pesticides; as well as from industrial and municipal wastes. Some pollution is natural, such as from mineral springs, lightning fixed nitrogen, etc. Even a pristine river will show considerable quality change between its source and the estuary. As indicated in Figure 1, the activities of man to protect or improve the quality of water are counter forces against natural pollution and man's normal tendency to pollute.

Our major concern, which is irrigation return flow, may be subject to augmentation and further pollution from sources not connected with irrigation; that is, precipitation, groundwater seepage, surface runoff from urban areas, highways, and non-agricultural lands and discharges from municipal and industrial sources which may commingle with irrigation return flow. Quantity, quality, nature, and extent of pollution from commingled waters have not been isolated or evaluated. This will be difficult, but is essential in order to properly assess the quality and pollution role of each water use affecting the total water supply.

Natural Pollution

Of the many possible natural pollutants, salts and sediments are likely of greatest concern to all users; however, under certain conditions, animal waste, plant nutrient, and toxic elements may become equally important. To irrigation agriculture and subsequent users of return flow, salt and silt create the most difficult problems.

Salt and sediments. Of the potential pollutants identified that may enter into the water supplies, the one of greatest concern to irrigation is salinity which is a natural product of geologic weathering. It is released from contemporary weathering, mineral springs, and seepage from areas of salt accumulation. Pillsbury (1) developed a relationship between water production and salt yield on several western watersheds. The salt production on streams varied from 0.1 ton per acre foot (a.f.) on streams producing 1,000 a.f./sq. mile to over 5 tons/a.f. on streams producing only 1 a.f./sq. mile. The Bureau of Reclamation has an active program to evaluate the quality of water of several river basins. Some of the results are indicative of the amount of salt loading resulting from natural sources, irrigation, and others (2,3,4). As indicated in Table 1, the salt from natural sources exceeds, in this instance, that from irrigation.

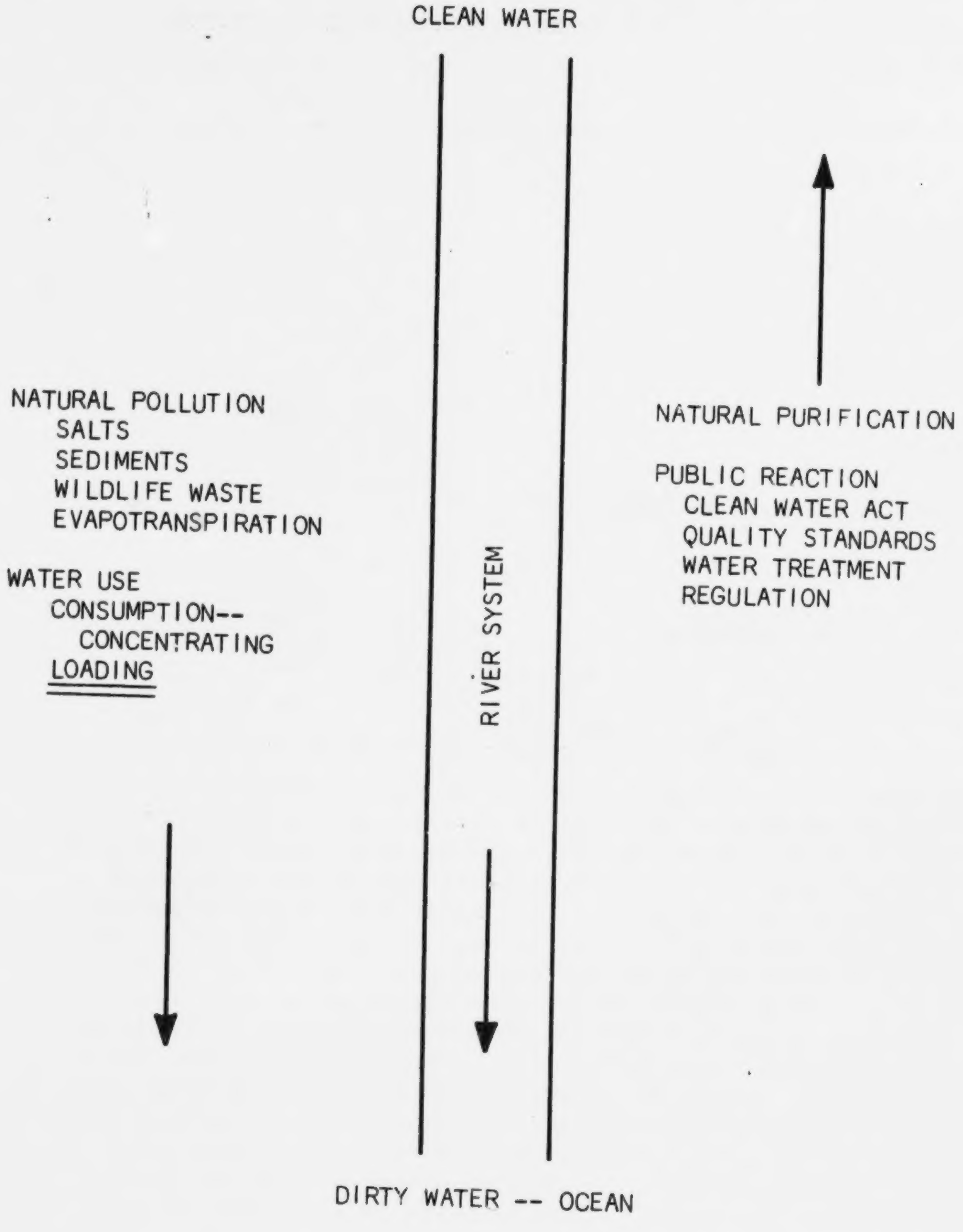
CLEAN WATER
NATURAL POLLUTION
SALTS
SEDIMENTS
WILDLIFE WASTE
EVAPOTRANSPIRATION
WATER USE
CONSUMPTION--
CONCENTRATING
LOADING
RIVER SYSTEM
NATURAL PURIFICATION
PUBLIC REACTION
CLEAN WATER ACT
QUALITY STANDARDS
WATER TREATMENT
REGULATION
DIRTY WATER -- OCEAN

Figure 1. Forces of pollution with counter forces.

TABLE 1

INCREMENTAL SALT CONCENTRATION ATTRIBUTABLE TO SPECIFIC SOURCES, COLORADO RIVER AT HOOVER DAM (5)

Sources	Total Dissolved Solids (mg/1)
Natural	
Diffuse Sources	274
Point Sources (mineral springs, wells, etc.)	69
Irrigation	
Consumption	88
Leaching	165
Municipal and Industrial Sources	10
Water Exports	22
Evaporation and Phreatophytes	97
	725

There is little concrete information on the amount of sediment resulting from wind and water erosion. (Erosion that would take place without man's influence.) As previously noted, climate is a factor responsible for some of the salinity and sodium problems found in the arid irrigated areas of the West. It can, likewise, have effects on other pollution. The amount and intensity of precipitation can influence the amount of erosion and the accompanying sediment load of the flow. Many of the watersheds are relatively unprotected by vegetative cover and are, therefore, subjected to considerable erosion when moisture falls on the land during high intensity storms. It is evident, however, that the sediment load resulting from natural erosion is much more sporadic than the salt load. In many of our arid basins only a small percentage of the land surface is irrigated having a large watershed acreage to produce salt and sediment loading of the river system. Van Denburgh and Feth (6) estimated the annual solute erosion in 11 important river basins. The wide range in tonnage was attributed to a complex of causes, among which were differences in geology, climatic environment, and the activities of man. Rates of solute removal were highest in areas of abundant precipitation and runoff, in contrast to rates of sediment removal, which are characteristically highest in basins subject to 10-15 inches effective annual precipitation. Storage dams on most river systems greatly modify the sediment problems.

Nutrients, toxic elements, and organics. Nitrogen is added to the system as a result of fixation by lightning and microorganisms, leaching from nitrate deposits, and the mineralization of organic matter. Phosphorus enters the system as a result of mineralization or organic matter, such as non-agricultural plant and animal wastes, release from sediments, and solution of natural phosphate minerals. Toxic elements, such as boron, enter the supply from natural deposits, usually by way of mineral spring waters.

Agricultural Pollution

The emphasis of the current discussion is on the effects of irrigation on water quality. As such, it is not possible to completely separate the pollution attributed to irrigation agriculture from the non-irrigated. It is also worthwhile to remember that while increasing salt concentration, the irrigation process may remove other pollutants introduced into the water supply from cities, farms, and industries. For example, nutrients and organic wastes deposited on agricultural land with irrigation water may be used by the crop, fixed by the soil, or degraded, so they are not contained in the irrigation return flow.

Salts and sediments. Salt pollution from agriculture is limited almost entirely to irrigated agriculture. Irrigation implies the extraction of almost pure water by the plants from the water supply with a resulting inevitable concentration of those dissolved solids which are characteristic of all natural water supplies. Whereas other uses add something to the water, irrigation basically removes water, thereby concentrating the salts. Irrigation may also add substances by leaching natural salts or other materials from the soil or washing them from the surface. Irrigation return flow is a mechanism, as illustrated in Figure 2, by which the concentrated salts and other substances are conveyed from irrigated agricultural lands to the common stream or underground supply. It includes bypass water, seepage, deep percolation losses, and tailwater runoff. The pollution effects of irrigation are different for each specific area or condition and depend on the concentration in the irrigation water, the proportion of the water leaching through the soils to that applied, the number of times the water is reused, and the amount of leaching from areas having residual salts. Salty groundwater and salt bearing shales serve as an abundant source of salt that may be loaded into the system both directly and indirectly by irrigation. It is this loading potential that makes it most difficult to estimate the salt concentration in the drainage water and the amount of salt loading that may be expected along a river system. This is also the reason why a salt balance for a given area is of little value as evident by the equation:

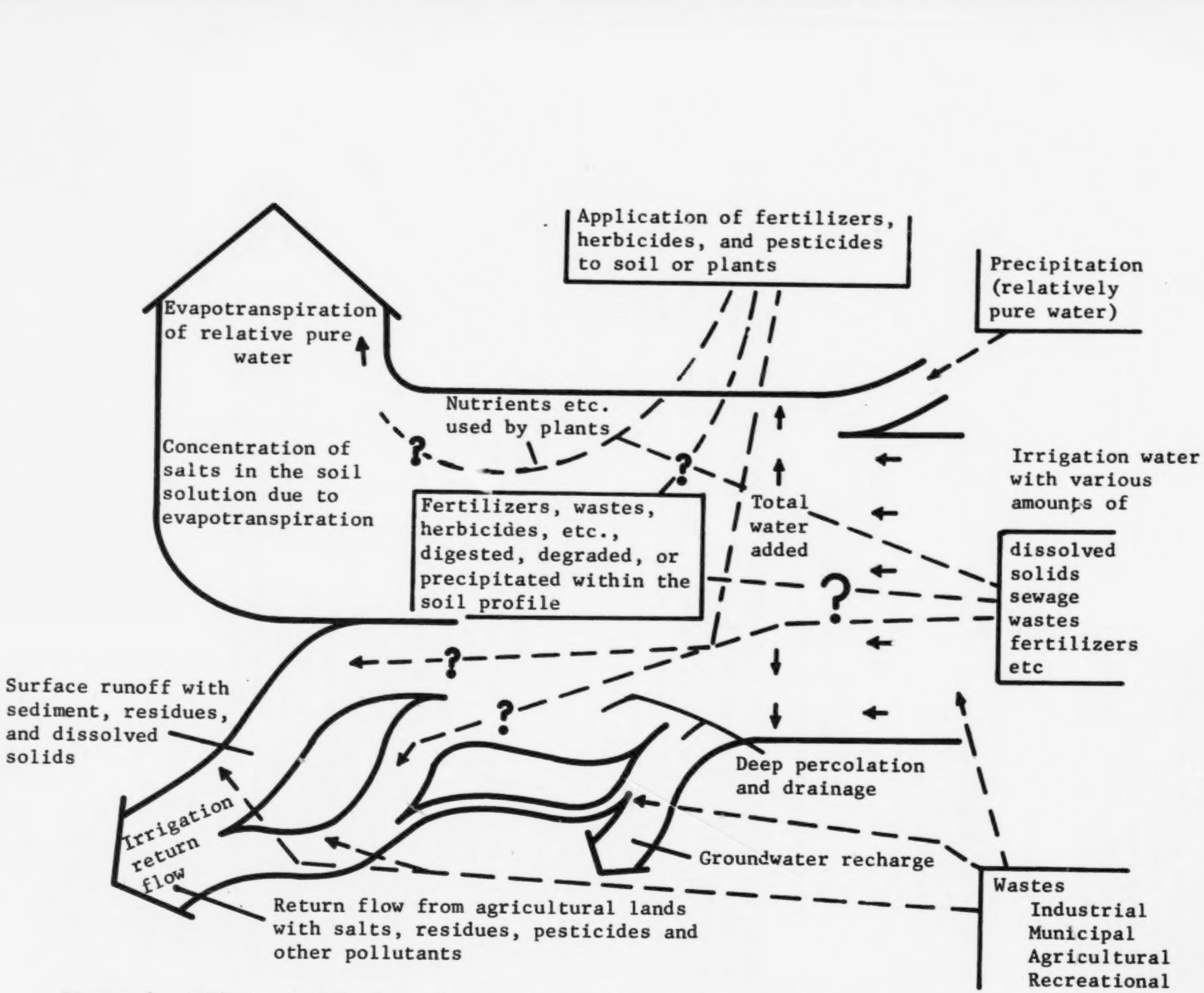
Application of fertilizers, herbicides, and pesticides to soil or plants
Precipitation (relatively pure water)
Evapotranspiration of relative pure water
Nutrients etc. used by plants
Concentration of salts in the soil solution due to evapotranspiration
?
?
Fertilizers, wastes, herbicides, etc., digested, degraded, or precipitated within the soil profile
Total water added
Irrigation water with various amounts of
dissolved solids
sewage
wastes
fertilizers
etc
?
?
?
Surface runoff with sediment, residues, and dissolved solids
Deep percolation and drainage
Irrigation return flow
Groundwater recharge
Wastes
Industrial
Municipal
Agricultural
Recreational
Return flow from agricultural lands with salts, residues, pesticides and other pollutants

Figure 2. Effect of the water-plant-soil complex on the quantity and quality of irrigation return flows.

$$S_{iw} + S_w + S_r - S_{ppt} - S_{dw} = 0$$

where:

S_{iw} = salt in the irrigation water

S_w = salt from contemporary weathering

S_r = residual salts

S_{ppt} = salt precipitated

S_{dw} = salt in the drainage water

There may be a balance for a basin, but much of the outgoing salt can come from the reserve rather than from the soil being irrigated.

The concentration of the salt in the soil solution will usually be in the range of 4-10 times the concentration of the irrigation water; and hence, the solution draining from the soil profile may be much higher in salt content than the water applied. Where the drainage from the root zone is impeded by a high water table, the concentration of the soil solution may be many times the concentration of the irrigation water. Fortunately, the concentration of salt in many irrigation waters is so low that the leachate under normal irrigation practice is much less concentrated than theoretically possible, and, when return to the stream or the groundwater body, the effect on the quality of the resulting water is not serious. The average increase in concentration in return flow is usually in the range of 2.5 to 7 times that of the source water. The scope of the problem of return flow is, therefore, limited from a practical standpoint to those areas and conditions where water quality becomes degraded to a point where it constitutes a nuisance, a hazard, or is of no value for further use.

Irrigated soils of the United States are scattered throughout, but the major areas are in the 17 western states. Within these, the areas most adversely affected by salt in the irrigation return flow are those in the lower reaches of the larger river systems of southwestern United States; those areas in the Lower Basin of the Colorado River, the Gila and Salt Rivers of Arizona, the Rio Grande in New Mexico and Texas, the San Joaquin River in California, and similar streams. In all of these river basins, there is a progressive deterioration in water quality as it flows downstream.

Nutrients and animal wastes. To understand the problem of pollution of waters with plant nutrients from fertilizers, it is necessary to understand the factors which affect the forms and solubilities of the plant nutrients and the manner in which these are transported. The nutrients of major concern as pollutants are nitrogen and phosphorus. Nitrate in the drainage water can originate from rain, dust, soil, organic matter, manures, an accumulation in the soils prior to irrigation, fixed by microorganisms, fertilizers, and from the wastes in urban and industrial runoff. It is removed from the soils by crops, denitrification, and in drainage waters. It is, therefore, difficult to determine the source of the nitrate in drainage waters.

The presence of plant nutrients in surface water is often attributed to a seemingly large tonnage of fertilizers applied to the land for maximum crop production. On much of the land, the amount of fertilizer applied is less than that used by the crop. A low average application, however, does not exclude the possibility of excessive amounts being used on a portion of the acreage. For some high value crops, such as celery, where the common practice is to make heavy applications of fertilizers, particularly nitrogen, coupled with frequent irrigation, it is likely that considerable nitrate may be leached with the excess water and appear in the waters of the drainage system. Doneen(8) concluded from a careful study in the San Joaquin Valley of California that in one field receiving heavy application of fertilizer a large portion of the nitrate in the drainage water was from the fertilizer. In two other fields recently drained, he could not come to the same conclusion because nitrates had been accumulating in the subsoil and groundwater for a long period of time. It is estimated that from combined sources, the nitrate-nitrogen content of the water in the San Luis drain is expected to be of the magnitude of 20 mg/1 (9).

Phosphate fertilizers can increase the phosphorus content of drainage water in several ways. Percolating water passing through a heavily fertilized sandy soil low in fixing capacity will carry soluble phosphorus into the drains. Fertilizers applied to the surface of soils tend to stay near the surface and saturate the "fixing" sites. When the fertile surface particles are eroded by wind or surface runoff, the phosphorus is carried with the sediments into the water system. There it equilibrates with the phosphorus in the water and may increase the concentration in solution unless the content of the water is at or above the equilibrium concentration. Biggar and Corey (10) speculate that runoff water in contact with fertile surface soils can pick up soluble phosphorus as it moves over the surface of the land, and the concentration of the runoff water might range up to a few tenths of a mg/1. Phosphate fertilizer can also have a more indirect effect. It can stimulate plant growth, and then parts of the plant, such as dried leaves, can be carried by wind or water into the drainage water where the plant material is mineralized by microorganisms, with the resulting accumulation of soluble orthophosphate in the water.

Johnston et al. (11) studied N and P losses in tile drainage effluents from a number of tile drainage systems in irrigated areas in the San Joaquin Valley of California. A number of cropping practices, with crops (cotton, alfalfa, rice), fertilizers and irrigation water applications as variables were involved in the study. Initial tile effluent analysis in a previously unirrigated noncropped area showed an N concentration of 1 mg/l. Another system that had been cropped to alfalfa and had a low discharge over the period of a year yielded a range of N between 2.0 and 14.3 mg/l. On systems where high rates of N fertilizer were applied, the concentrations ranged up to 62.4 mg/l. In the systems reported, the range of concentrations of nitrates went from 1.8 to 62.4 mg/l with a weighted average of 25.1.

Both nitrogen and phosphorus can be carried directly into the surface drains with the tailwater from fields where the fertilizer is being applied in the irrigation water. Another likely source of nutrient pollution is the animal wastes in the runoff from pastures and feeding lot operations being included in drainage waters. Pollution can also come from non-irrigated agricultural land. The runoff water would be expected to contain very small amounts of salts, and other pollutant loading would be similar to the runoff from irrigated land. Erosion, with the resulting sediment load, plant nutrients, and pesticides would be sporadic and greatly influenced by the intensity of precipitation.

The rapid growth of large animal-feeding operations has resulted in a tremendous increase in the potential pollution hazard from domestic animal wastes. A recent report (12) states: "Animal wastes in this country probably exceed wastes from any other segment of our agricultural-industrial-commercial-domestic complex." The Department of Agriculture (13) has estimated that over 1.5 billion tons of animal wastes are produced annually, one-third of which is liquid, and as much as 50 percent coming from concentrated production operations. From the USDA population equivalent values, it is evident that a feedlot operation with 10,000 cattle will produce wastes equivalent to a city of 164,000 people. A city of this size will use over 8 million gallons of water per day to carry its wastes while the feedlot seldom uses large quantities of water to carry the wastes. Untreated municipal sewage may have a biochemical oxygen demand (BOD) of about 100 to 400 mg/l. Runoff from cattle feedlots produced by rainfall is a very high strength organic waste and may have a BOD content as high as 10,000 mg/l (13,14) depending on rainfall amount and intensity, antecedent moisture conditions, slope and surface conditions of lot, degree of deterioration of wastes, and other factors. It has been further demonstrated that feedlot runoff is a source of high concentrations of bacteria normally considered as indices of sanitary quality (14). Other pollutants arising from animal wastes are the nutrient compounds of nitrogen and phosphorus, and mineral salts. It is difficult to predict the magnitude of the pollution problem in drainage systems induced by animal wastes. It is safe to assume that there is a considerable amount of such pollution, and that the drainage lines and ditches provide conveyance routes to the waterways.

Pesticides. Pesticides are recognized potential pollutants in water. As with nutrients, the origin is not restricted to agricultural usage. Pesticides are used in the cities, industrial areas, in forests, as well as on the farmland. They can enter the water by direct application from drift during application or be washed from adjacent lands adsorbed to the eroded sediments. In a similar manner, pesticides can also pollute the waters of irrigation return flow. There is nothing unique about pesticide pollution and irrigation, except perhaps where pesticides are used to control weeds and insects along irrigation canals and open drains.

Many of the pesticides used are sorbed chemically and physically by the soil particles. Those thus sorbed are not likely to enter subsurface waters. LeGrand (15) reporting on movement of pesticides in soils suggests that it is likely that most all pesticides in streams result from overland flow. Nicholson (16) in discussing pesticide pollution control states:

> The two principal sources of water pollution by pesticides are runoff from the land and discharges of industrial waste, either from industries that manufacture or formulate pesticides or from those that use these compounds in their manufacturing processes. Less important causes of pollution are (i) activities designed to control undesirable aquatic life, (ii) careless use of pesticides, and (iii) occasional accidents in transportation.

Johnston et al. (17) analyzed drainage effluent from systems located on irrigated land in the San Joaquin Valley of California. On experimental areas, the insecticides DDT, Parathion, and Lindane had been added. Only relatively small quantities of chlorinated hydrocarbon residues were found in effluent from open drains where both surface and subsurface drainage waters were collected. Traces of residue were found in the irrigation water applied to tile drained farms. When the concentration factor was considered, that is, depth of irrigation water applied/depth of drainage water removed, on a unit basis, the total quantity of insecticide residue in tile drainage effluent did not exceed and was generally less than the total quantity of residue applied in the irrigation water. Tailwater, or surface runoff, contained from 7 to 12 times as much residue as the applied water when DDT was applied to the land and as much as 85 times more residue than the irrigation water when Lindane was applied to the land. Relatively large concentrations of residue were found in the surface soil of the area studied.

As a generalization, it appears that the chlorinated hydrocarbons, such as DDT, persist in soils (18,19) and do not move in appreciable concentrations through the soils and into drainage effluent as groundwaters. Movement is primarily with suspended sediment, either organic or inorganic materials in streams and open drain flow. The thiophosphates, such as Parathion, decompose rapidly and do not persist in soils or water.

Pesticides can be transported in the air while applications are being made and be deposited in waters remote from the area of application (20). Wind can remove surface soil to which pesticides are adsorbed and be deposited by rain or the settling dust.

Faulkner and Bolander (21) have found large numbers of nematodes including plant parasites in irrigation and drainage waters. There is no indication yet as to the nature and magnitude of any pollution problems that might accompany the treatment of water for the control of nematodes.

Indirectly, pesticides may add other pollutants to soils and water. The organic phosphorus insecticides and miticides readily decompose in soil and release soluble phosphorus. Other organic pesticides are composed of compounds containing mercury, zinc, manganese, copper, chromium, cadmium, and tin. When the organic compounds are decomposed, the metal ions are released.

Municipal and Industrial Pollution

The occurrence of municipal and industrial wastewaters in water supplies used by irrigated agriculture may be the result of incidental discharges into a common receiving water subsequently used for irrigation or from direct, intentional application of such wastewaters as a prime source of supply. In either case, the nature and concentration of any constituent that may be considered as a potential pollutant will depend upon the specific characteristics and origin of the wastewater; that is, whether (a) of purely domestic origin, (b) a combination of domestic and industrial origin, or (c) essentially an industrial discharge. In addition, the characteristics of the wastewater may be ameliorated by the degree of treatment and/or dilution afforded the effluent.

Municipal effluent. Several studies of mineral increments from community use have been made, and an example of data reported is shown in Table 2. In another study (22), the salt pickup in the sewage system of the City of Los Angeles was 635 mg/l. The most important potential pollutants in municipal wastewater effluents affecting an irrigation supply would include total dissolved solids, sodium, chloride, and boron. Even one use of water could increase the boron content above the tolerance limits for some crops. Recycle a few times and the boron content would almost certainly be too high for most crop plants.

Industrial wastewaters. Characterization of industrial wastes is exceedingly difficult for several reasons: (a) the numerous different water using and waste producing variety of industries, (b) the wide range and spectrum of potential pollutants that are involved, sometimes

TABLE 2

MINERAL INCREMENTS IN DOMESTIC WASTEWATER FOR 15 CALIFORNIA COMMUNITIES (23)

Analysis (mg/l)	Maximum Range	Normal Range Domestic Sewage
Dissolved Solids	1200	100-300
Boron (B)	3.8	.1-.4
Percent Sodium (percent)	42	5-15
Sodium (Na)	290	40-70
Potassium (K)	22	7-15
Magnesium ($CaCO_3$)	110	15-40
Calcium ($CaCO_3$)	250	15-40
Total Nitrogen (N)	42	20-40
Phosphate (PO_4)	50	20-40
Sulfate (SO_4)	75	15-30
Chloride (Cl)	550	20-50

varying significantly within the same industry, and (c) the paucity of factual data available on the volumes and pollutional characteristics of many industrial wastes. An example of important water using industries and associated pollutional characteristics of the wastewaters is shown in Table 3.

Potential pollutants of industrial origin that are of particular concern to irrigated agriculture include: (a) total dissolved solids, sodium, and chlorides, (b) boron, (c) heavy metals, (d) pesticides, (e) radioactivity, and (f) numerous organics.

Recreational Wastes

Pollution from recreational activities are probably the least delineated of all sources. It may not greatly influence the quality for irrigation, but it certainly does influence the quality of water for other uses. Man's activity is responsible for human wastes at campsites and indirectly from summer homes. Fishing, boating, and production of wild game all contribute. The building of roads, trails, homesites, etc. expose the soil to erosion which may well be the most serious form of pollution attributed to recreation.

Quality Changes from Irrigation

The only certain change in water quality caused by using water for irrigation is the increase in the concentration of soluble salts. How much this change will be depends on variables at each specific location.

TABLE 3

SOME SIGNIFICANT CHEMICALS IN INDUSTRIAL WASTE WATERS[1] (24)

Chemical	Industry
Acetic acid	Acetate rayon, pickle and beetroot manufacture.
Alkalis	Cotton and straw kiering, cotton manufacture, mercerizing, wool scouring, laundries.
Ammonia	Gas and coke manufacture, chemical manufacture.
Arsenic	Sheep-dipping, fell mongering.
Chlorine	Laundries, paper mills, textile bleaching.
Chromium	Plating, chrome tanning, aluminum anodizing.
Cadmium	Plating.
Citric acid	Soft drinks and citrous fruit processing.
Copper	Plating, pickling, rayon manufacture.
Cyanides	Plating, metal cleaning, case-hardening, gas manufacture.
Fats, oils, grease	Wool scouring, laundries, textiles, oil refineries.
Fluorides	Gas and coke manufacture, chemical manufacture, fertilizer plants, transistor manufacture, metal refining, ceramic plants, glass etching.
Formalin	Manufacture of synthetic resins and penicillin.
Hydrocarbons	Petrochemical and rubber factories.
Hydrogen peroxide	Textile bleaching, rocket motor testing.
Lead	Battery manufacture, lead mining, paint manufacture, gasoline manufacture.
Mercaptans	Oil refining, pulp mills
Mineral acids	Chemical manufacture, mines, Fe and Cu pickling, DDT manufacture, brewing, textiles, photoengraving, battery manufacture.
Nickel	Plating.
Nitro compounds	Explosives and chemical works.
Organic acids	Distilleries and fermentation plants.
Phenols	Gas and coke manufacture, synthetic resin manufacture, textiles, tanneries; tar, chemical and dye manufacture, sheep-dipping.
Silver	Plating, photography.
Starch	Food textile, wallpaper manufacture.
Sugars	Dairies, foods, sugar refining, preserves, wood process.
Sulfides	Textiles, tanneries, gas manufacture, rayon manufacture.
Sulfites	Wood process, viscose manufacture, bleaching.
Tannic acid	Tanning, sawmills.
Tartaric acid	Dyeing; wine, leather and chemical manufacture.
Zinc	Galvanizing, plating, viscose manufacture, rubber process.

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[1] Reproduced by permission Butterworths. "River Pollution. 2: Causes and Effects," Klein.

Some of these are: (a) the proportion of the water consumed, this is dependent on irrigation efficiency, number of times the return is reused, etc., (b) the amount of residual salts leached from the soil profile, (c) the amount of salt carried into the drainage system by seepage from canals, storage reservoirs, etc., and (d) the amount of salt loading of drainage effluent from other unidentified sources.

The probable changes in salinity and other pollutants are indicated in Table 4. These are the changes that are likely to occur when water carrying the pollutants comes in contact with soil surface or passes through the profile. As noted, the probable effects are very different depending on whether or not the water passes through the soil and whether or not the concentration is high in the original water.

Problems of Irrigation Agriculture

The users are concerned with the overall degradation of water quality and the presence of specific pollutants that can adversely affect the value of water for irrigation as well as for other uses. Regardless of the source of pollutants, water quality should be evaluated for potential hazards to crops and soils before being used. The harmful effects of salt and the specific effects of sodium, chloride, arsenic, boron, and the heavy metals have been well established (25).

Different pollutants have very diverse and changing effects on the value of water. This is illustrated in Figure 3. Salts generally decrease the value more or less in proportion to the concentration increase; however, there are broad critical ranges where the user is forced to change the type of crop, and then there may be a sharper value decline for a given increment of salt. This can continue until at some concentration the water can no longer be used for irrigation and must be disposed of or treated. At such a concentration, there is a change from a small positive value to perhaps a large cost depending upon the method of treatment or disposal.

The effects of other pollutants on value may be more nearly as indicated for some specific toxicants. Whether it be the salt concentration or the amount of some other pollutant that makes treatment or disposal necessary, there is then an effect on the value of plant nutrients which may abruptly change to a liability. The situation in the San Joaquin Valley of California is an example where there is a large cost for disposal of return flow waters. One cost is for removal of plant nutrients before the water can be discharged into San Francisco Bay and the other in the construction of the San Luis Drain to convey the water to the Bay (26,27). There are, of course, in some instances less costly alternatives, such as discharge into a water fowl refuge where it may have some value or directly into a dead sea or lake where the water may have limited value but is not necessarily a liability.

TABLE 4
PROBABLE CHANGES IN QUALITY AS A RESULT OF IRRIGATION

Quality Factors	Irrigation Return Flow	
	Surface	Subsurface Drainage
Salts (TDS)	Not greatly different from sources	Concentration increased usually 2-7 times. Depends on amount in the supply, number of times reused, the amount of residual salts being removed, and the amount from non-agricultural sources.
Sodium and Chloride Ions	Relatively unchanged.	Both proportions and concentration likely to increase.
Nitrate	More likely a slight increase than a decrease and highly variable.	Likely to decrease if the content in irrigation water is high and increase if amounts are low. Greatest hazard from heavily fertilized porous soils over irrigated.
Phosphate	Content may increase, but closely correlated with erosion of fertile topsoil.	Decrease if considerable in source. Not likely to greatly increase.
Pesticides	Highly variable content. Surface waters subject to polluting. Likely associated with amount of erosion.	A reduction in many instances. Concentrations likely to be low.
Pathogens and other Organisms	Variable and may increase or decrease.	Low content with a likely reduction in most all pathogens. Other organisms may increase or decrease.
Sediments and Colloids	Often more than in source but may be less--highly variable.	Little or no sediment or colloidal materials in the flow.
Organics	Manures, debris, etc., likely to increase	Most oxidizable and degradable materials to decrease.
Heavy Metals	Kinds and amounts are variable. Likely to be greater than in subsurface flow.	More likely to decrease in concentration.
Sewage Effluent	Not greatly changed except by filtering and oxidation effect of crops if sprinkled.	Concentration of all pollutants reduced except common soluble salts.

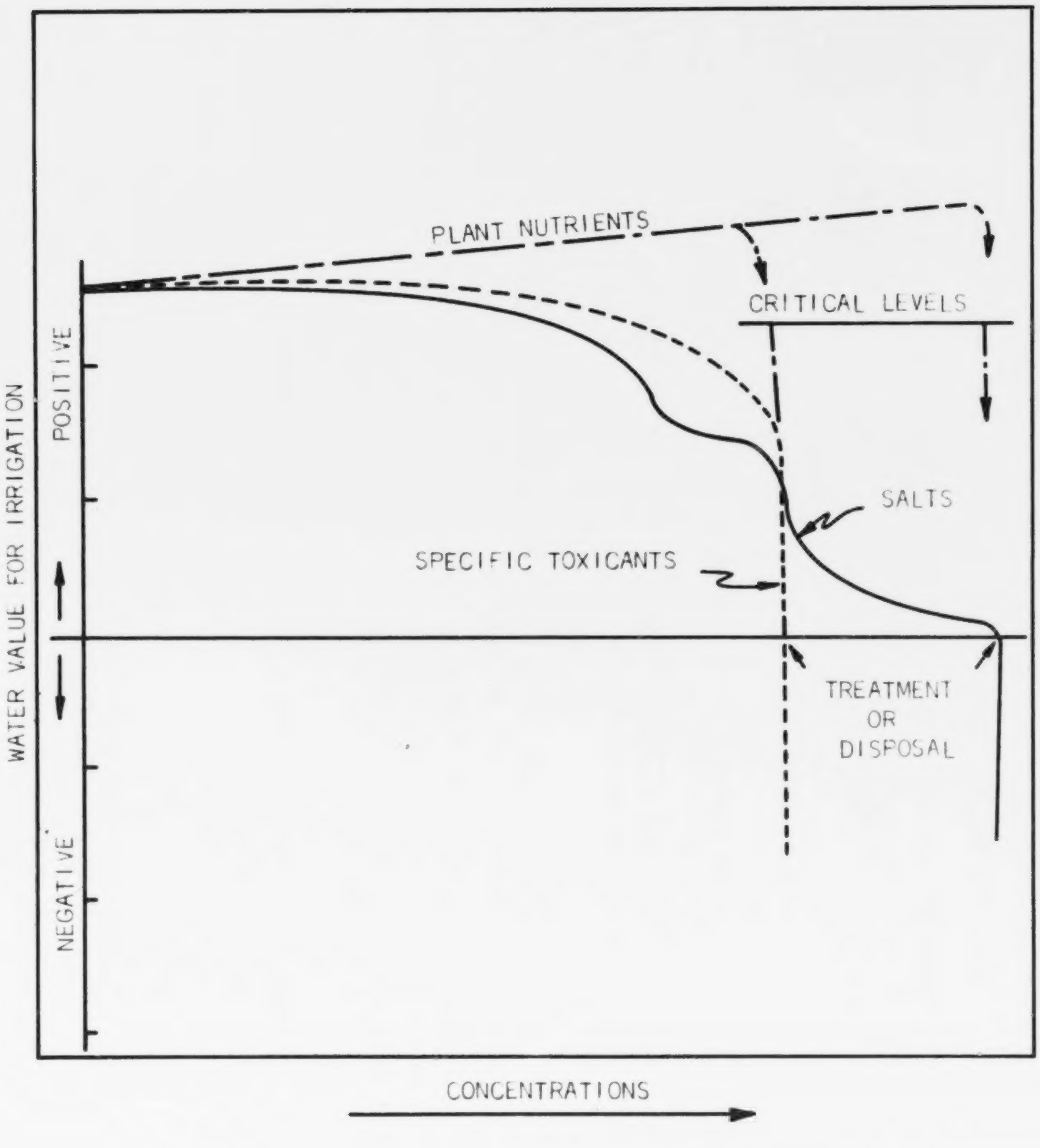

Figure 3. The effect of different kinds of pollutants on the value of water for irrigation.

Quality Control of Return Flow

The concentrating of some pollutants, such as salts, is an inescapable consequence of consumptive use of irrigation water. There are, however, possibilities for regulating the concentration. On the other hand, the loading of a stream with pollutants can, in some instances, be more nearly controlled.

Concentrating Salts

Even though it is not possible to prevent concentrating salts, it is theorectically possible to regulate the concentration of the return flow. This is by some form of dilution of which there are several: (a) regulating the amount of applied water that is returned to the system (regulating the amount and time of leaching), (b) importing water for direct dilution or alternative uses, (c) increase the water supply by weather modification, and (d) desalt some of the water and use for dilution.

Such activities as increasing the supply by weather modification and desalting introduces new problems. More water by increasing precipitation will undoubtedly bring more salt and sediment from the watershed. This will depend on where and how the increase comes. Brine disposal is a problem created when water is desalted somewhere along a river system.

Loading Effects

Considerable of the salt loading effects can be reduced by diverting salty water from the supply. This may include diverting natural salty water as well as seepage waters that have accumulated salt. Establishing a drainage network whereby most of the drainage water is from the soil profile offers some hope for reducing loading. In such a system the soil would be managed so as to keep the salty groundwater below the active drains and, thereby, reduce the amount of loading. Lining of canals, ponds, etc., to prevent seepage and leaching from non-irrigated soil is another practical method. Exclusion of lands containing appreciable amounts of residual salts or pre-leaching of such soils and diverting the drainage waters also prevents the addition of salt to the system. Drainage waters from new lands usually contain the greatest amounts of salts because of the salt in the profile not previously exposed to leaching water.

The loading of pesticides, plant nutrients, and sediments can largely be controlled by preventing the erosion of the top soils and runoff. We recognize that there will be spillage and accidental discharge as well as movement of some soluble pollutants through the soil and into the drainage waters.

The identification of kinds, amounts, and sources of pollutants and utilizing the mentioned control methods may appear relatively simple. This would not be a proper evaluation of the situation. The salinity problem alone is highly variable and as expressed by the Bureau of Reclamation:

> Each irrigated area has a different effect on quality depending upon properties of the soils and substrata in the drainage area, number of years the land has been irrigated, number of times return flow is reused, nature of the aquifers, rainfall, amount of dilution caused by surface wastes, temperature, storage reservoirs, vegetation, and types of return flow channels.

It is our opinion that loading of heavy metals and boron by industry and domestic users offers major hazards to irrigation agriculture. There is no known method of detoxifying the soil once critical levels of heavy metals have been reached. Boron compounds have many uses; and hence, there are many sources of contamination. It is very harmful to plants at low concentration--levels well below the tolerance levels to man and animals

Beneficial Effects

Not all of the effects on the quality of return flow are adverse. The soil can improve the quality by: (a) filtering suspended solids, (b) removal of heavy metals, pesticides, and phosphate by chelation, sorption and/or precipitation, (c) degrading detergents, wastes and other organics, and (d) by providing the death time for harmful microorganisms. Such benefits can be used to counter the disadvantages resulting from the consumption of water. Eliminating irrigation within a basin may reduce some of the salt loading and concentrating of the salt, but certainly would not eliminate the salt problems, and it could increase some of the problems created by other pollutants.

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WATER QUALITY REQUIREMENTS AND RE-USE OF WASTEWATER EFFLUENTS

by

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Although the Federal role in water pollution has evolved over a 65-year period, there has not been a very long history of interest or concern with the subject of wastewater reclamation. In fact, many of the primary and secondary sewage treatment processes in use today were known some fifty years ago, and it was not until the early 1960's that the degradation of our waters as a resource became a national issue.

This awareness, occasioned through the accumulated and continuing effects of rapid economic and population growth, culminated in the passage of two very important and far-reaching laws -- (1) the Water Quality Act of 1965 which required that standards of water quality be established, implemented and enforced for all interstate and coastal waters of the United States, and (2) the Clean Water Restoration Act which provided for the Federal Government's participation in financing needed treatment plants and in undertaking, fostering and sponsoring needed research, development and demonstration efforts.

Under these laws, the 50 states have proceeded to establish standards of water quality for each of their interstate waters, and many States have further chosen to establish such standards for their intrastate waters as well. The standards are not uniform across the country, but vary as you might expect according to individual circumstances relating to climatic zone, hydrogeologic factors, present water quality, and a host of other location-related variables. There are only two uniform guiding principles: (1) the standards for any given river, or stretch of river, must spell out the beneficial uses which the public expects to make of the water resource (i.e. recreation, fishing, municipal or industrial water supply, etc.) and (2) the criteria chosen to support such uses (i.e. dissolved oxygen content, temperature, pH, etc.) must be adequate to protect and in fact enable such uses to be made.

The establishment of river uses and criteria has profoundly affected the philosphy of water quality management on a national scale. This has been particularly true in the case of wastewater treatment for pollution control. In the United States, to date, treatment requirements have been usually expressed as removal efficiencies. The removal efficiencies in turn have been almost directly related to specific treatment operations or processes. However, the stated purpose of the Water Quality Act of 1965 is to "enhance the quality and value of our water resources." Treatment requirements become more meaningful when

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They are expressed in terms of quantities of impurity when the objective is attempting to protect water quality. Therefore, requirements are moving to the concept of specifying the total quantity of impurity which may be discharged into receiving water. The means of accomplishing that quantity are being determined by the industry or the municipality, because in most cases, it is this quantity which impairs the quality of the stream.

It is now recognized that specification of the quantity of impurities is the only means to maintain the quality of the receiving water where there might be an increase in wastewater flow. Thus, as population grew or industrial activity increased, more effective treatment or control devices would have to be installed in order to meet the established quantity requirement.

Brief reflection upon the dual problems of water supply (quantity) and water pollution (quality) should manifest the inseparable bond which exists between them. If water were used only once and then disposed of, any degree of water quality degradation would be inconsequential. But, except in rare cases, reuse does occur in some form. Gone are the days when man can readily depend upon the hydrologic cycle, upon dilution, or upon natural purification to restore the quality and quantity of his water source. Thus, when one user degrades the water quality so as to deny reuse to the next user, the latter's water supply is diminished by that amount.

By restoring the quality of waste effluents to higher and higher degrees, the point is reached when they can be deliberately and directly, or indirectly, reused for any beneficial purpose, even for potable water. In addition to alleviating pollution, the renovation of wastewater can simultaneously augment the water supply. Thus the concept of complete water renovation solves the problems of water pollution and water supply, simultaneously.

Presently, heavy reliance is placed on secondary treatment of municipal wastes and its equivalent for industrial waste to achieve and maintain, in a reasonably short time frame, the quality of water as it is specified in the standards for the receiving water. The standards for each State include a so-called "Implementation Plan," which is usually a listing of specific needs to install new secondary sewage treatment plants or upgrade and improve existing primary plants for given locations and in a given time frame. At some locations, however, plans of the States call for primary treatment only; at others, even secondary treatment will not suffice to restore quality, or to maintain it in the face of expected future economic and population growth, and the plans call for the installation of tertiary, or "advanced waste treatment."

From the overall view of potential water supply shortages in the United States, advanced waste treatment has the greatest promise at locations where the municipal wastewater is presently discharged into the ocean or other sink and is thus lost for reuse. These locations include some of the largest American cities, such as New York, Los Angeles and San Francisco, where population concentrations are high, and where it is becoming increasingly costly to follow the conventional approach of reaching out into more remote interior locations to import additional water supplies. This also includes the arid and semi-arid regions where treated effluents have not been reused.

One of the largest alternative sources of water available to a city is the wastewater which it has thus far thrown away. As a rule of thumb, some 60% to 90% of the water delivered to a city is returned to waste discharge. If treated to the conventional secondary level, this water contains usually less than 0.1% of impurities, and advanced waste treatment can further serve to make it completely suitable for a wide range of reuses.

The United States learned a lesson in this regard during the severe drought of 1965 in the Northeastern Region. New York City was particularly hard hit; air conditioning was shut off; businesses shut down or lost customers; restaurants could serve a glass of water only upon request. Yet 3 billion gallons of unused water were flowing down the Hudson River into the ocean each day -- about three times the amount consumed daily by the City. The water was unusable because it was polluted.

Emergency conservation measures were instituted immediately to relieve the most pressing hardships. Studies were started to consider the alternatives available to secure additional fresh water supplies to prevent a recurrence of water shortages in the future. Sea water desalting and waste water purification were the two most important alternatives to importation from the interior watershed.

Not surprisingly, desalting came out second best to advanced waste treatment. A feasibility analysis of a 100 million gallons per day advanced waste treatment plant which could be added to an existing secondary sewage treatment plant showed that the plant could be constructed for $33 million (at then-prevailing prices and interest rates) and would produce and deliver potable water into the City's system at about 16 cents per 1,000 gallons. The costs for the desalting alternative were considerably higher. It is likely that this desalting cost disadvantage will continue in most locations, if only for the simple reason that sea water contains some 3.5% of dissolved salts plus some organic matter -- equivalent to more than 35 times as much foreign matter as secondary sewage effluent.

The advanced waste treatment facility postulated for the New York City situation envisioned the following steps:

A. A second stage, intensive biological treatment process would be installed following the existing high rate activated sludge treatment. This second stage bio-oxidation would provide more than 90%

removal of all biochemically oxygen-demanding (BOD) organic compounds entering the treatment plant. In addition, the 3.5-hour additional aeration would eliminate essentially all of the ammonia and organic nitrogen from the waste stream.

B. The effluent from the biological treatment process would be subjected to a coagulation-sedimentation and sand filtration sequence similar to that utilized in conventional water treatment plants. These purification procedures are capable of removing both suspended and colloidal particles to produce a sparkling clear water. The alum coagulation also serves to reduce bacterial and viral disease-producing organisms.

C. From the filters, the water would pass through deep beds of granular activated carbon which will adsorb residual dissolved organic impurities from the water.

D. While this series of purification steps will yield a high quality water, a final positive disinfection step, complete with fail-safe provisions and a very large factor of safety, would be imposed. The disinfection step would employ three separate chlorination contactors; while one is being filled and another emptied, the third will provide an absolutely certain contact with free chlorine. This batch or fill-and-draw system would eliminate even a remote possibility of inadequate contact time for bacterial and viral control.

E. Quality of the product water would be continuously monitored and, in fact, the entire plant would be highly instrumented both for control and for quality monitoring purposes to assure the complete safety and reliability of the operation.

F. The product water would be pumped through a 1000-ft. force main to an existing but presently unused shaft, extending downward directly to the city's principal water distribution tunnel to Brooklyn and Queens, and injected into the tunnel at a pressure of 150 psi. The tunnel now carries 400 to 600 million gallons of tap water each day which would provide a dilution factor of at least 3:1 for the renovated water. The combined supply would be completely potable in every respect and should meet or exceed the highest Public Health Service Drinking Water Standards.

The treatment process proposed for New York City is only one of many alternative systems available. The final system selected depends on the use of the water and the impurity to be removed.

In returning to the broader effort in the United States to research, develop, and demonstrate new technology for sewage treatment, this discussion will attempt to categorize the effort in general terms first, and then proceed to the specifics. Basically, our most urgent needs fall into two broad categories:

(1) We need treatment processes for more effective removal of organics, nutrients, and suspended solids, which are now only partially removed by "conventional" treatment; and

(2) We need processes for the removal of dissolved pollutants not ordinarily removed at all by "conventional" treatment. Within and across these two broad categories, two lines of attack are being pursued:

(1) Modifications of "Conventional" Processes; and
(2) "Advanced" or Tertiary Processes

Now to the specific efforts underway:

I. MODIFICATION OF CONVENTIONAL PROCESSES

In this category some eight projects are now in the design or construction stages, and three projects are already in operation.

A. Modification of the Activated Sludge Process for Increased Nutrient Removal

At Manassas, Virginia, and at three locations in California (Santee, Irvine, and Chino), these study efforts are underway:

1. Nutrient removal through biological oxidation; involving very high organic loadings in the aerators and rapid solids-liquid separation.

2. Progressive bio-oxidation, aerobic oxidation of nitrogen compounds to nitrates, followed by anaerobic conversion of nitrates to nitrogen gas.

3. Three-stage nitrification-denitrification; high-rate activated sludge process, treatment with sludge enriched with nitrifying bacteria, denitrification with anaerobic bacteria.

B. Combined Trickling Filter - Activated Sludge Process

At Dallas, Texas, and Ventura, California, projects are underway to evaluate tandem use of both processes in different sequences to determine how trickling filters must be supplemented by additional treatment to produce satisfactory effluent.

C. Dual-Train Experimental Activated Sludge Plant

At Washington, D. C.; one train to furnish effluent to tertiary processes, the second to study modified activated sludge processes. (Operates in conjunction with existing tertiary pilot plant.)

D. Polymer Addition to Activated Sludge Process for Phosphorus Removal

At Washington, D. C.; an operational project involving addition of three polymeric materials to raw sewage to increase sedimentation of solids in primary settling tanks. Evaluation of effects of this treatment throughout plant, including the anaerobic digesters.

E. Mineral Addition to Activated Sludge Process for Phosphorus Removal

At Pomona, Santee and Irvine, California; lime precipitation and ammonia stripping for treatment of digester supernatant; addition of sodium aluminate to aerator; single-stage tertiary clarification and filtration using lime or alum as coagulant; Dorr-Oliver process involving chemical and biological methods for phosphate removal from raw wastewater, with lime recovery and reuse.

II. TERTIARY PROCESSES

Some ten tertiary treatment research and demonstration projects are operational in various parts of the United States, and another nine are in the design or construction stage. The areas under investigation include the following:

A. Chemical Coagulation, Sedimentation, Filtration, and Granular Carbon Adsorption - Emphasis on tertiary processes to reduce suspended nutrients and organics because they contribute so heavily to the overall water pollution problem.

B. Direct Carbon Treatment of Secondary Effluent - For removal of organics from clarified secondary effluents.

C. Ammonia Stripping - Countercurrent air contacting lime-clarified secondary effluents containing nitrogen as ammonia as organic forms.

D. Electrodialysis - Lime coagulation and granular adsorption precedes effluent passage through electrodialysis stack; 40% of dissolved salts removed with a wastestream only 10% of feedstream.

E. Ion Exchange - Parallel operation of electrodialysis unit for comparison of process economics.

F. Reverse Osmosis - Different membrane configurations tested on same wastewater to achieve higher flux rates and product-to-waste ratios, with critical determination of pretreatment techniques necessary to prevent fouling and deterioration of membranes.

Summary of Research Progress Achieved to Date

A wide range of wastewater treatment processes have been evaluated from laboratory-scale through pilot-scale in recent years. The treatment methods investigated include processes for suspended solids, organic and inorganic removal, nutrient removal, and, conjuctively, certain aspects of the biological processes. A number of processes have been studied extensively enough to assess their feasibility with a fair amount of accuracy.

For wastewaters with appropriate mineral composition, lime clarification will effectively remove suspended solids and the nutrient phosphate. Alum clarification is expected to be successful at a cost of 8 cents/1,000 gallons at the 10-mgd plant. For organics removal, activated-carbon treatment is promising. Granular carbon treatment without clarification of the feed can be carried out for about 8 cents/1,000 gallons or less at the 10-mgd level on high quality secondary effluent. Powdered carbon treatment has been estimated to cost about 12 cents/1,000 gallons at the same plant capacity, provided the carbon can be reactivated; this treatment yields a highly clarified water. For removal of gross inorganic content, electrodialysis treatment should be possible for about 16 cents/1,000 gallons or less in a 10-mgd plant, although pre-treatment appears to be a necessity. Ion exchange will cost about 25 cents under the same conditions. Reverse osmosis has great promise for effective results. It is still in a developmental stage and costs are difficult to estimate. Removal of nitrogen, either as ammonia or nitrate, is a difficult problem. An air-stripping process for ammonia may be technically feasible at 3 cents/1,000 gallons or less for a 10-mgd plant, but requires lime clarification to adjust pH to 11 or above. Studies of denitrification of a highly nitrified effluent on granular stone or sand shows promise for nitrate removal at 3 cents/1,000 gallons for a 10-mgd plant. Electrochemical treatment appears at present to be economically unfavorable.

The Outlook

In summary, a great deal of research progress has been made, and the outlook for the future is bright. A range of processes have been evaluated and improved to the point where the designers of new systems have a great range of technological options in selecting efficient treatment processes for various wastewater streams and effluent qualities. We must depend on current and future studies, however, to provide the optimum process selection.

As in the past, the economics of particular processes and combinations will greatly influence the design and selection of individual systems. The costs set forth in the table below apply to a 10-mgd plant and include amortized construction, operation and maintenance costs; they are projected best estimates for the tertiary processes shown, and are based on actual experience for the conventional primary and secondary treatment stages.

Process	Cost (cents/1,000 gallons)
Conventional	
Primary treatment	7.5
Activated sludge	11
Filtration	
Microscreening	1.5
Coarse Media	2.5
Fine Media	3.5
Phosphate Removal	
Mineral Addition to Aerator	3
Coagulation, Sedimentation (lime ovalum)	7
Coagulation, Sedimentation, Filtration	10
Ammonia Stripping	3
Granular Carbon Adsorption	4 - 8
Dissolved Inorganic Removal	
Electrodialysis	14
Reverse Osmosis	25
Ion Exchange	25

In summary, advanced treatment for the removal of nutrients, organics, and inorganics can be accomplished for about 26-30 cents/1,000 gallons compared to 11 cents/1,000 gallons for secondary treatment. However, the wastewater reclaimed by the improved or advanced treatment has economic utility and value as related to the reuse application selected for it, and, by logical extension, becomes once again available for sale to the user.

As a final word about economies of scale for the electrodialysis and reverse osmosis dissolved inorganic removal processes, pre-publication results of current work by Interior's Office of Saline Water indicates that a 30-mgd plant located in a Southern California could demineralize secondary effluent at 21 cents/1,000 gallons for the electrodialysis process, and at 22 cents for the reverse osmosis process, both at 1968 prices.

SALINITY CONTROL IN RETURN FLOW FROM IRRIGATED AREAS
A DEMONSTRATION PROJECT

by

Norman A. Evans [1]

The Upper Colorado River Basin comprises approximately 220,000 square miles in the states of Utah, Colorado, New Mexico, Arizona and Wyoming. The main stem of the Colorado River heads in Colorado at the Continental Divide and runs more than 500 miles southwestward through Utah and Arizona to a place called Lees Ferry, which marks the division between the Upper Colorado River Basin and the Lower Colorado River Basin. This river and its tributaries literally is the lifeline of southwestern United States.

Although problems abound in the utilization of the water, none is considered so great as the mineral degradation which occurs as the water flows westward. This problem is serious because the basin is approaching conditions of full development and utilization of the available water supply.

The seriousness of mineral pollution in the Colorado River is illustrated by the 1963 salinity crisis at the U. S.-Mexico border arising from saline drainage from the Welton-Mohawk irrigation project. Here, as a solution, the federal government provided a waste canal to carry the return flow from the project around Imperial Dam. Such drastic measures cannot be expected to be used to solve other salinity problems along the river. Methods and practices must be developed which will afford control of the salt load in the river while permitting continued use of the water.

Salts in the river accumulate from several sources but the heaviest contributor is water returning to the river from underground drainage after it has been used for irrigation on lands near the river.

Figure 1 represents a typical geologic cross section along the upper Colorado River. Note the shale base material over which has been deposited alluvial material which now constitutes the irrigated soil. This figure also shows a water budget, indicating water applied as irrigation on the land, seepage losses from the canal, deep percolation into the ground water of a fraction of the irrigation water applied, and evapotranspiration into the atmosphere of a part of the irrigation water applied. Lastly, a component of the irrigation water applied is shown running back to the river as surface runoff.

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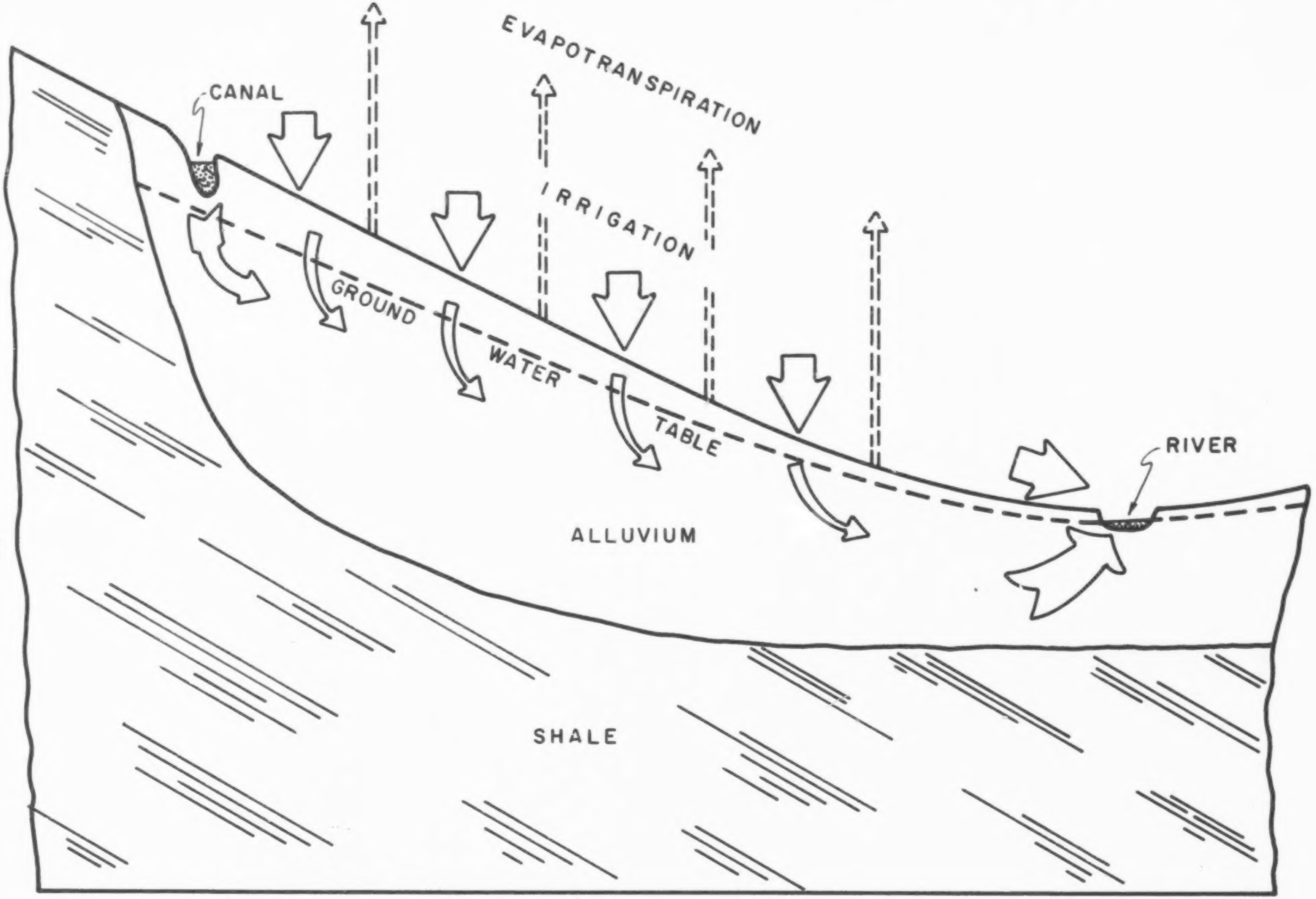
EVAPOTRANSPIRATION
IRRIGATION
CANAL
GROUND WATER TABLE
RIVER
ALLUVIUM
SHALE

FIGURE 1 - TYPICAL GEOLOGIC CROSS SECTION

Water returned to the atmosphere by evapotranspiration leaves behind in the soil any salt which it contained when it was applied to the land. That salt residue left behind may be dissolved by deep percolation water and carried back to the river. This is one source of salt load returning to a river and in some cases, especially where the irrigation water contains a heavy load of salt, can contribute a large salt load. Seepage from a canal passing through the soil as it moves toward the river may also dissolve salts from crystalline form in the soil and thereby gain a load of salt. These two processes by which salt is added to return flow might be called (1) evapotranspiration residue, and (2) solution pickup.

In the Upper Colorado River the irrigation water has relatively low salt load, on the order of 300 ppm, so the evapotranspiration residue is relatively small. On the other hand, solution pickup is relatively high because the parent material and base material contains large amounts of crystalline salt. Figure 2 shows electrical conductivity ($ECX10^3$) and exchangeable sodium percentage (ESP) in soils and shale of Grand Valley.

Figure 3 is the Upper Colorado River Basin showing the main stem and principal tributaries. The numbers show the annual salt load at three points expressed in tons. At Cameo, Colorado, the annual salt load is 1,549 tons. At Cisco, Utah, the annual salt load is 4,242 tons. The Gunnison River at Grand Junction adds 1,519 tons. Quick arithmetic shows that the salt load gain in this section of the main stem of the Colorado River is 1,174 tons. This is almost equal to the load at Cameo and is primarily the result of solution pickup in return flow from irrigated land along the river.

The purpose of this paper is to summarize a demonstration project which has been initiated in the Grand Valley area (Figure 3) for the purpose of showing that saline agricultural return flows are controllable and that if improvements in water management practices are applied, the salt load returning to the river will be reduced.

Mechanics of Return Flow

Before describing the demonstration project, a brief discussion of the nature of return flow will be helpful. Figure 4 represents a typical irrigated area along the river. Phreatophytes are illustrated because the water-loving plants are almost invariably found along western rivers. Now let us look at the hydrograph of return flow as computed from a 2-dimensional mathematical model. Figure 5 shows the return flow during and after the irrigation season. Note that the return flow is negative at first. The water table at time zero is assumed horizontal and the negative return flow represents phreatophyte withdrawal of water from the river. However, as the groundwater rises, flow returns to the river reaching a peak shortly after the irrigation season ends and gradually declining thereafter. Let's look now at the

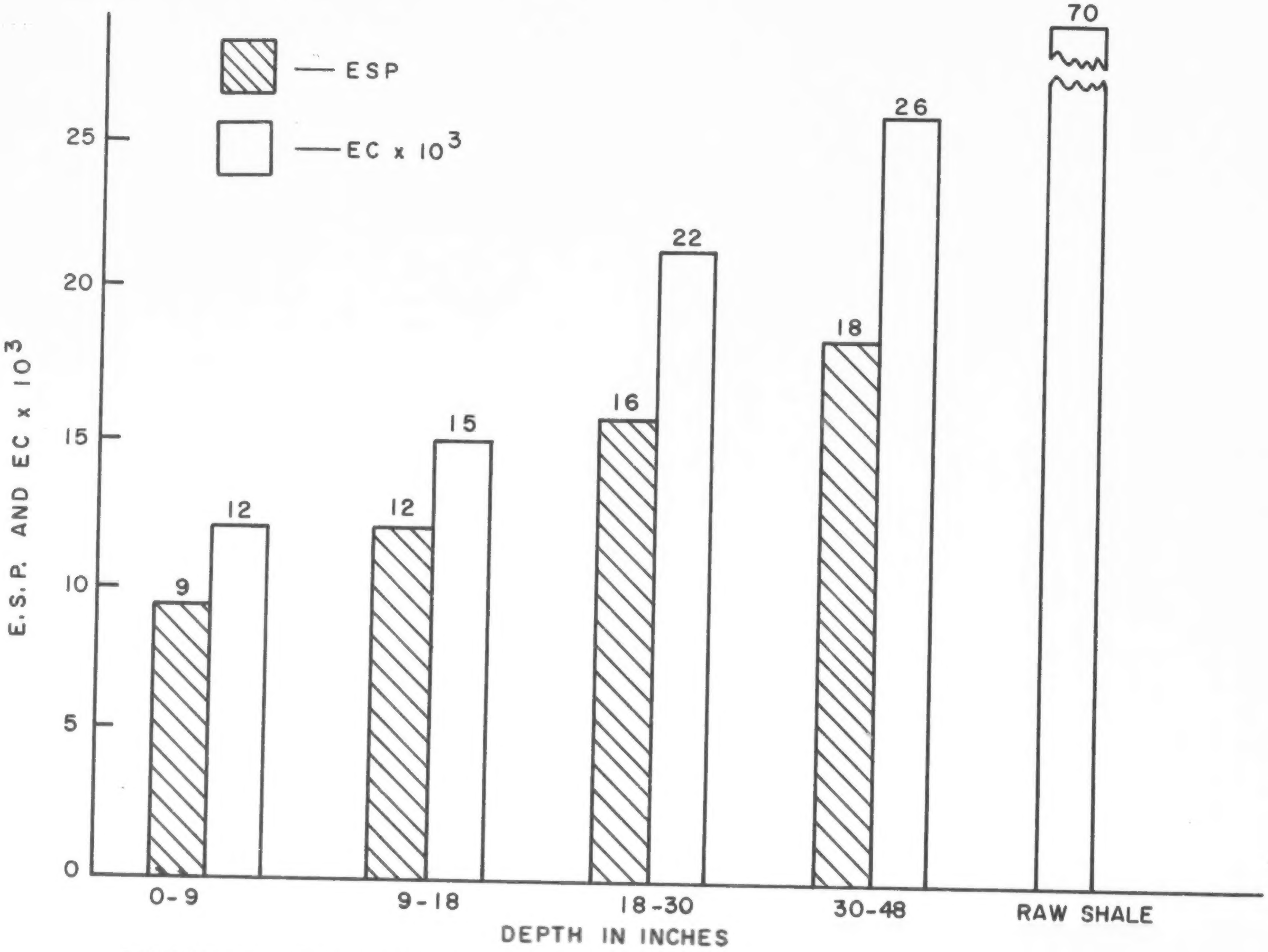

FIGURE 2 — SALT STATUS OF SOILS AND SHALE

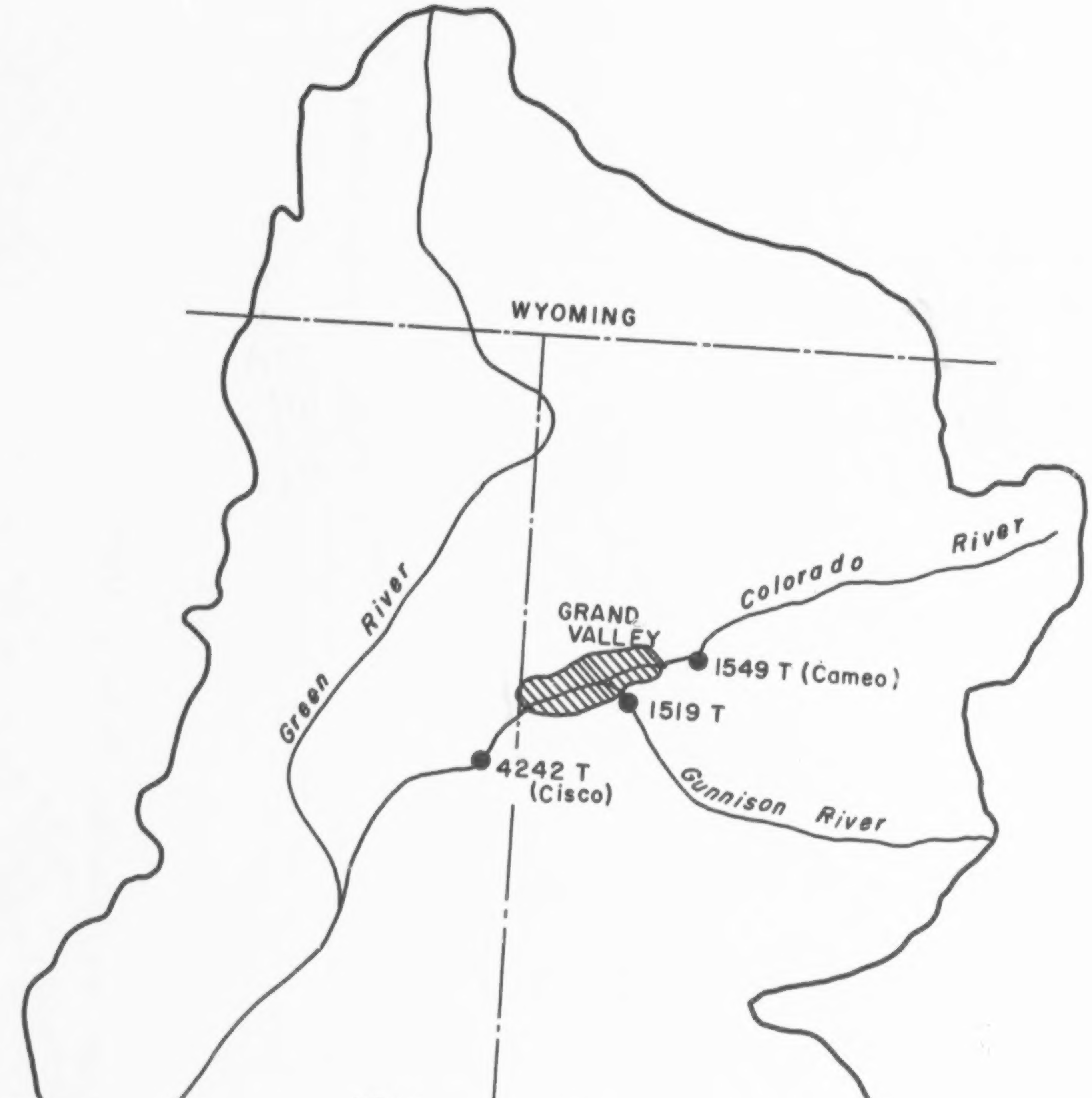
WYOMING
Green River
Colorado River
GRAND VALLEY
1549 T (Cameo)
1519 T
4242 T (Cisco)
Gunnison River
UTAH
COLO.
ARIZ.
N. MEX.
8642 T (Lee's Ferry)

FIGURE 3 – UPPER COLORADO RIVER BASIN

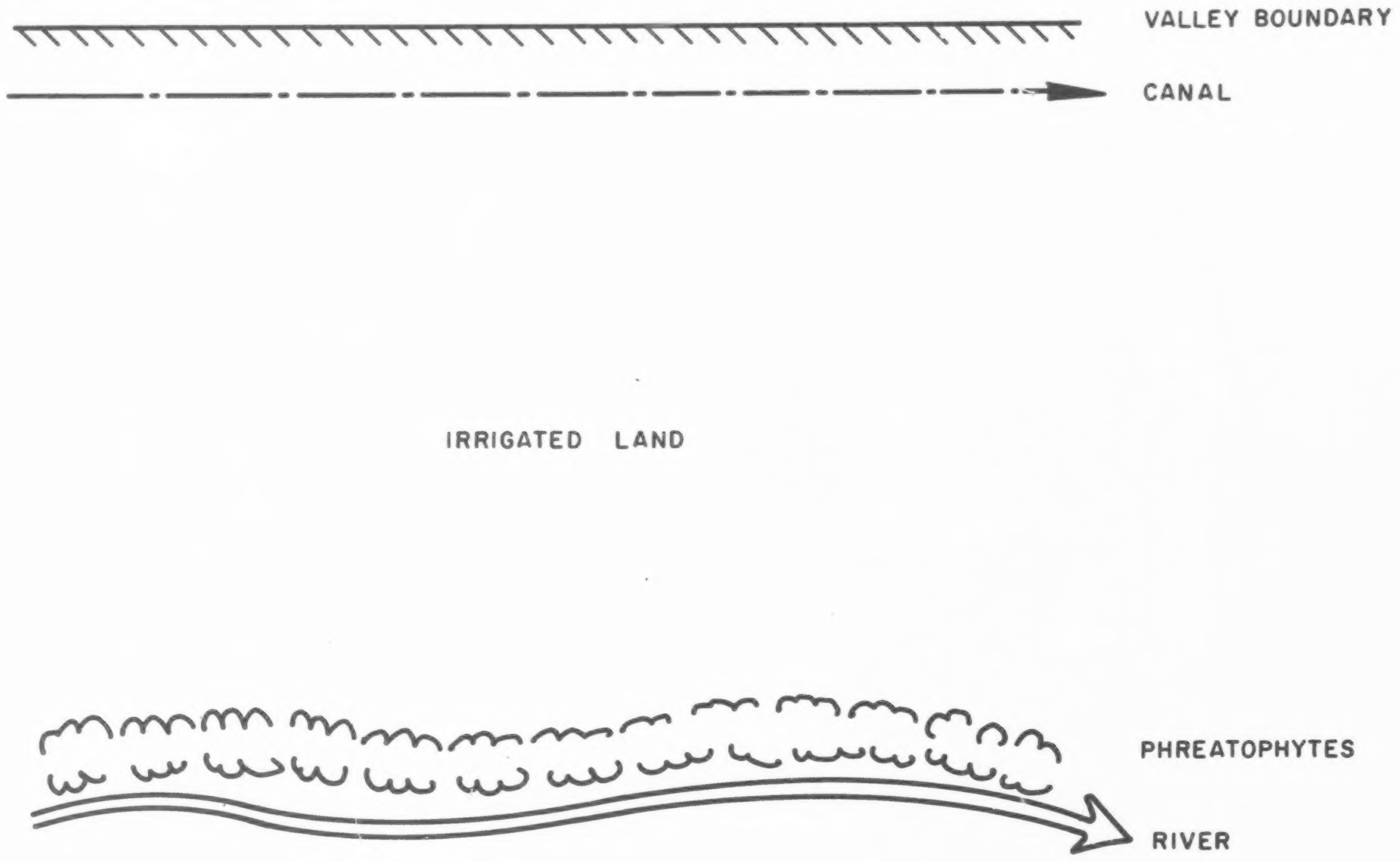
VALLEY BOUNDARY
CANAL
IRRIGATED LAND
PHREATOPHYTES
RIVER

FIGURE 4 - IDEALIZED IRRIGATED AREA

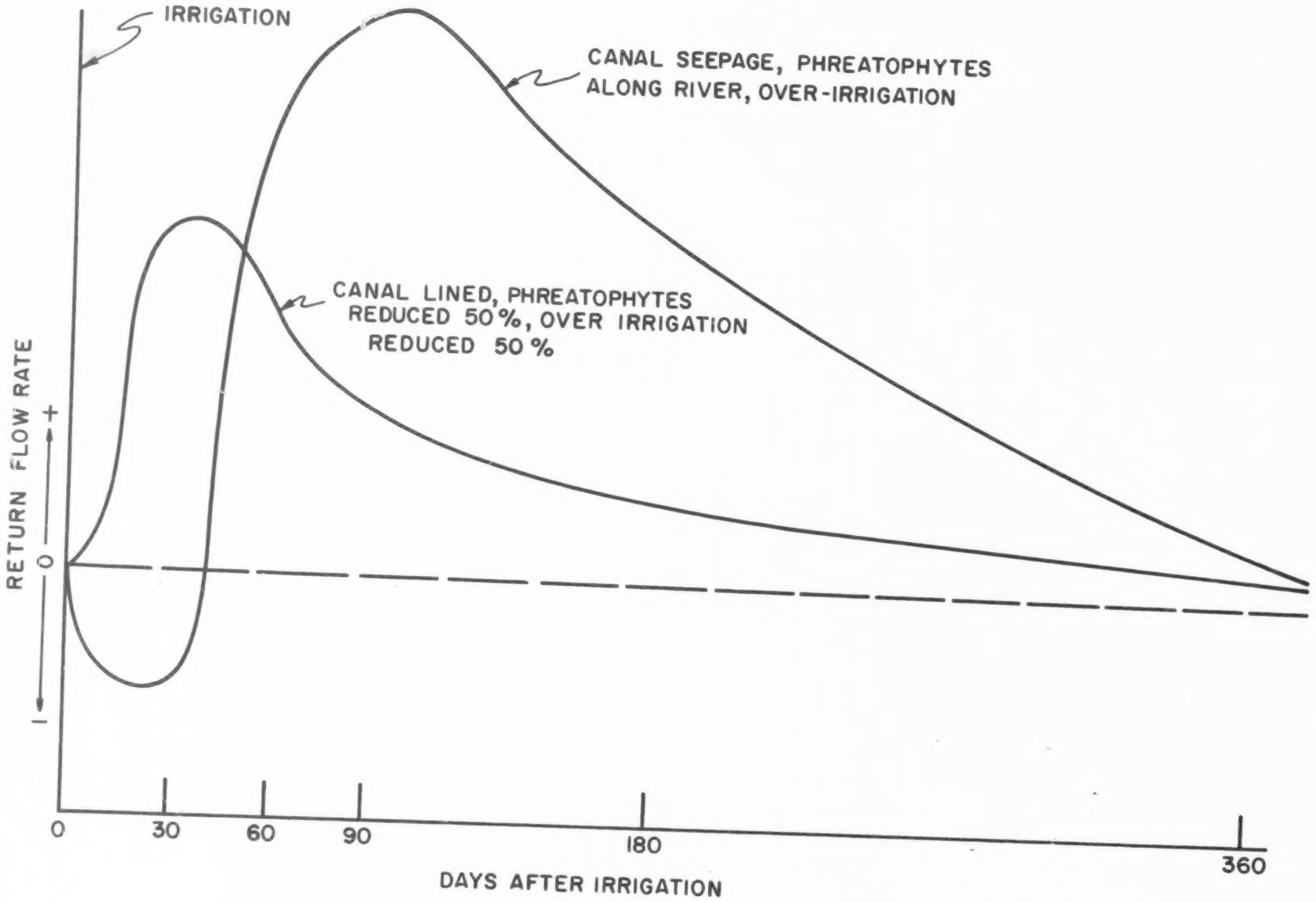

FIGURE 5 - HYDROGRAPHS OF RETURN FLOW

effect of improved water management by eliminating canal seepage, reducing the area of phreatophytes by 50 percent, and reducing the amount of deep percolation by 50 percent. By eliminating canal seepage, we notice first that the peak runoff is smaller and occurs earlier. Comparing the areas under the two curves indicates a reduced total volume of return flow. It has been frequently observed that salt load in return flow is proportional to volume of water returned, so we might expect a reduced total amount of salt to enter the river.

The mathematical model has been used also to illustrate the effect of system geometry on return flow. Figure 6 shows a river valley with the main canal located one-fourth the distance from the river to the valley boundary. Canal seepage is considered for a given period of time and the resulting hydrograph of return flow is displayed. Note that it has a high peak rate of return dropping off rapidly. The second case locates the canal at the valley boundary. This is generally more typical of the Colorado River Valley. The same amount of seepage during the same time is reduced and the return flow hydrograph is seen to be much flatter and with the peak occurring much later. Of course both situations return the same volume of water to the river but with a different rate distribution. Unfortunately, we know very little about the effect of return flow rate on solution pickup.

Demonstration Project

A demonstration project to show effects of seepage reduction on salt load was proposed by the principal water-using identities in the Grand Valley near Grand Junction, Colorado. Six irrigation companies, a power company, and a drainage district combined resources to form a corporation for the purpose of conducting the demonstration and study. They received a grant from the Federal Water Pollution Control Administration for construction and project evaluation. A contract was in turn negotiated by the corporation with Colorado State University for assistance in evaluating the results of the project. The study area is represented in Figure 7.

The first step in the evaluation program was a "before treatment" inventory of water and salt budget in the demonstration area. Canal seepage losses have been measured and a plan for lining certain sections of canals is being formulated. This lining will be constructed during the forthcoming winter season prior to the 1970 irrigation season. An "after treatment" inventory will be made during and after the 1970 season.

Water Budget

Water flow measurement in all canals, ditches, and drains leading into and out of the study area are being made using a wide variety of measuring methods. Measuring flumes have been used in some places, existing structures have been calibrated for measurement in others, and dye-dilution has been used for measurement where other methods

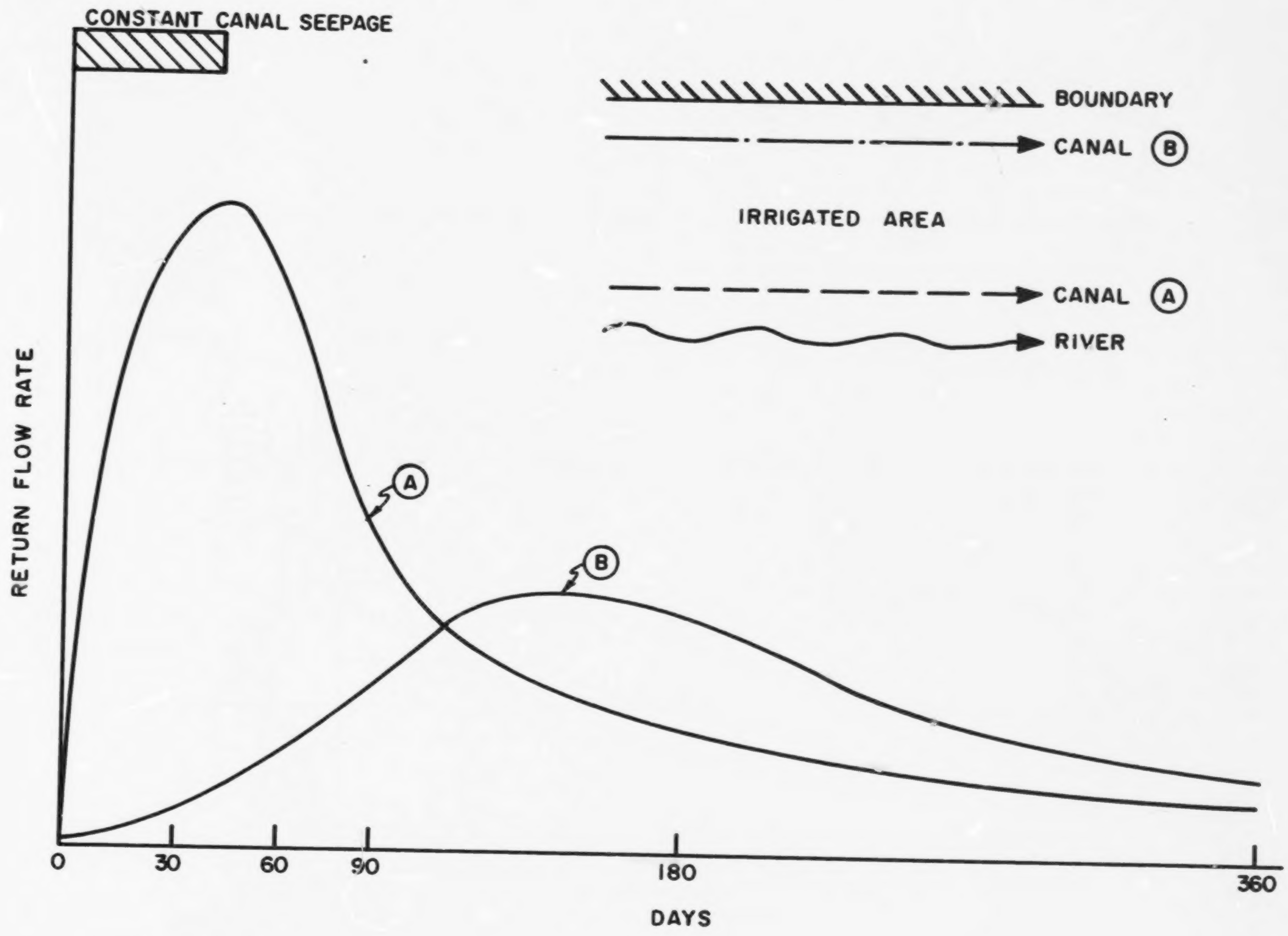

FIGURE 6 — INFLUENCE OF CANAL LOCATION ON RETURN FLOW

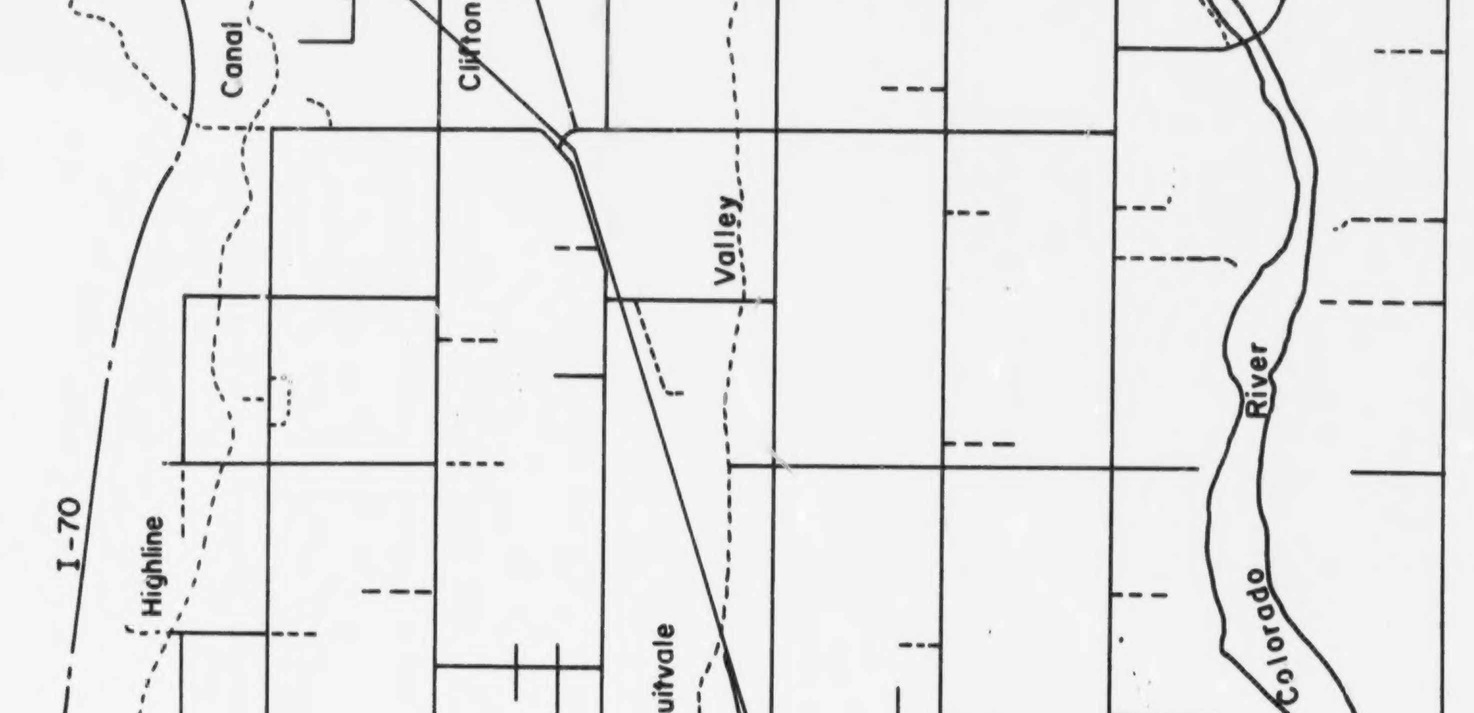
I-70
Highline
Canal
Government
Grand
Clifton
Fruitvale
Valley
Canal
6-24
Colorado
River

FIGURE 7 — STUDY AREA

were not possible. Evapotranspiration estimates will be made from a survey of vegetation type and density. The estimate will be made by the Jensen-Haise method of calculation.

Groundwater flow will be calculated from hydraulic gradient and permeability data. A grid of piezemeter installations has been made with which the groundwater flow net can be measured. Permeability measurements in situ by standard methods will also be made. River flow measurements upstream and downstream from the demonstration area also will be made.

Salt Budget

Salt monitoring the river will afford the final evidence of positive benefit from reduction in canal seepage. However, the lag time in return flow for this particular system is uncertain so salt monitoring in the groundwater will also be performed. A grid network of porous cups has been installed in the alluvium at several depths from which groundwater samples will be extracted. Changes in salt flux at these sampling points will add evidence as to the effect of reduced volume of groundwater flow.

Summary

Water users in the Grand Valley area of Colorado have long recognized the damaging effects of canal seepage and excess water application in irrigation. They have seen it in the progressive deterioration of agricultural land beginning shortly after irrigation was introduced to the area. They also recognized river quality deterioration which has been outlined in these remarks. With the cooperation and assistance of the Colorado Water Conservation Board and the strong interest of the Federal Water Pollution Control Administration, these citizens set about doing something about it through a demonstration project financed by FWPCA. Canal seepage will be reduced. This should reduce by 1/2 the volume of return flow, and affect a significant reduction in salt load originating from solution pickup. We believe also the attention focused upon water management through this demonstration will result also in greater effort toward better irrigation water management on farms which in turn will further reduce return flow volume.

While return flow control will reduce salt load, a certain amount is essential for maintenance of salt balance and we do not suggest that elimination of all return flow is an objective - rather its control to satisfy salt balance requirements.

It is expected that the experience gained in this project will serve as a guide to other similar areas along the entire Colorado River as well as other areas of the western United States.

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WATER QUALITY CONTROL PROBLEMS IN INLAND SINKS

by

Richard C. Bain, Jr. and John T. Marlar [1]

INTRODUCTION

All rivers do not flow to the oceanic sea; some create their own unique inland seas in the desert. Desert lakes like desert lands are harsh, and few life forms survive. The tenuous balance between vegetative cover and precipitation, animal life and water supplies in arid lands is reenacted with different players in the desert lake. Here survivors from a wetter past or newcomers introduced by man, struggle in the specialized environment created by rivers without outlets.

The arid lands of the western United States contain numerous closed river basins, or inland sinks, which have unique water quality and ecological problems. Each of these basins will support an inland sea which typically is increasing in salinity, has fluctuating water levels and various ecological problems associated with salt, nutrients or pesticides often from agricultural drainage. Since these sumps are rarely or never flushed, the trend is toward ecological imbalance as a result of salt buildup.

Figure 1 is a comparison of recent salinities in six well-known inland sinks in the Western United States. These inland seas are in various stages of "aging" as far as water quality is concerned. Several of these seas are becoming more saline at a rate faster than nature alone would dictate, because the freshwater inputs have been reduced or made more saline by man. Pyramid Lake in western Nevada is a good case study illustrating the effect of inflow reductions on the aging process. The Salton Sea, in southern California receives relatively saline inflows comprised of drainage from irrigated lands. The water quality and quality related problems affecting aquatic life resources of these rather different desert lakes will be described to emphasize the unique water quality management problems which occur in inland sinks.

PYRAMID LAKE

Background

Pyramid Lake is the largest remaining remanant of ancient Lake Lahontan. Its present area of 100,000 acres is only one-fiftieth that of its Pleistocene ancestor. Pyramid Lake has been appropriately

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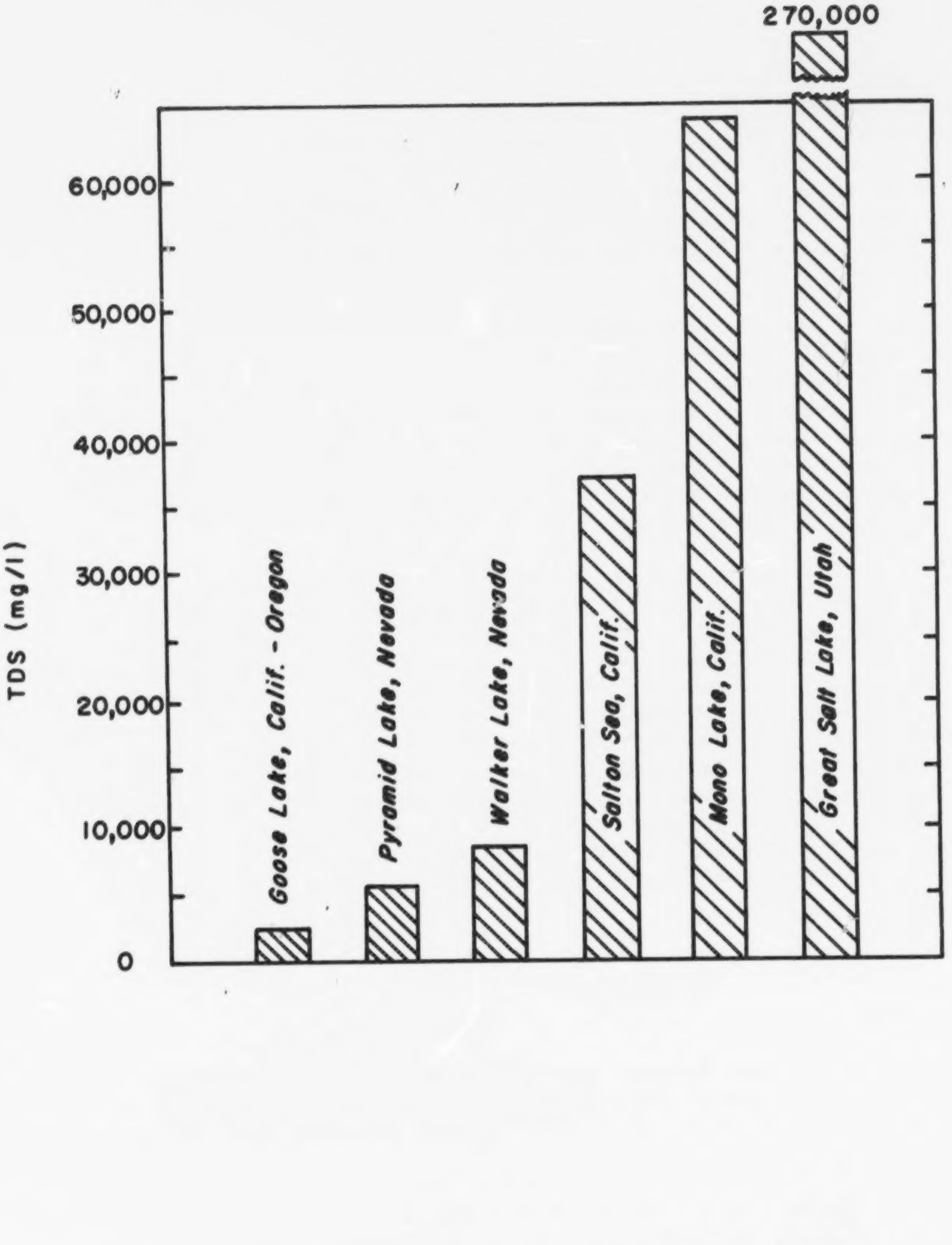


FIGURE 1 - SALINITY OF SIX INLAND SINKS

called North America's most beautiful desert lake. Set at an altitude of 3,800 feet in the practically barren Nevada desert, it is indeed a rewarding sight to view its vast expanse of blue-green waters ringed by peaks of brown. It is a welcome relief from the surrounding arid lands.

The life blood of any lake is its water source. The Truckee River which originates in Lake Tahoe and flows past Reno, Nevada, has been the major source of water to Pyramid Lake (Figure 2). The River apparently supplied sufficient water to the Lake to result in a reasonably constant surface elevation in Pyramid Lake until 1910 when Truckee River water was diverted at Derby Dam, the first reclamation project undertaken in the West by the U. S. Reclamation Service, now the U. S. Bureau of Reclamation. Truckee River water is diverted to the Carson River Basin where it is stored in Lake Lahontan for use by the Truckee-Carson Irrigation District. Drainage from the District flows to the Stillwater Wildlife Refuge in the Carson Sink. Although there are some additional diversions from the Truckee River upstream, the diversion at Derby Dam has been the most important single factor affecting Pyramid Lake in this century.

Prior to 1910 the entire flow of the Truckee River was tributary to Pyramid and Winnemucca Lakes. Based upon data and analyses assembled by Harding (1) the total flow reaching the two lakes during the period 1780-1905 averaged 546,000 AF/Yr. After major diversions for irrigation purposes began in this century, Lake Winnemucca received no overflows from Pyramid Lake and finally evaporated to dryness in 1939. Recent discharge of the lower Truckee River tributary to Pyramid Lake (1957-67) has averaged only 223,000 AF/Yr. (2).

When the diversion of Truckee River water through the Truckee Diversion Canal started, Pyramid Lake held over 35 million acre-feet and had a surface area estimated at over 120,000 acres. Since that time, due to the unbalanced water budget, the Lake has increased in salinity by about 50 percent, receded some 80 feet in depth, lost 15 million acre-feet in volume, and 20,000 surface acres. Figure 3 shows salinity trends based on several data sources (1,3,4). During the 1940's the famous Lahontan Cutthroat trout disappeared from the Lake. It was erroneously concluded by biologists at that time, that the increase in dissolved solids had become toxic to the trout. However, in 1948, experiments demonstrated that trout could survive lengthy exposure to Pyramid Lake water. The lowering of the Lake surface had caused an increase in the gradient of the lower Truckee River and a shallow delta formed at the River's entry to the Lake which blocked the access of the trout to their spawning areas in the River. Thus streambed changes caused by the lowering of the Lake had caused the population of cutthroat trout to disappear. Restocking programs have since been initiated by the Nevada Fish and Game Commission.

Although the ultimate tolerance of Lahontan Cutthroat trout to dissolved solids has not been adequately defined, it is known that certain

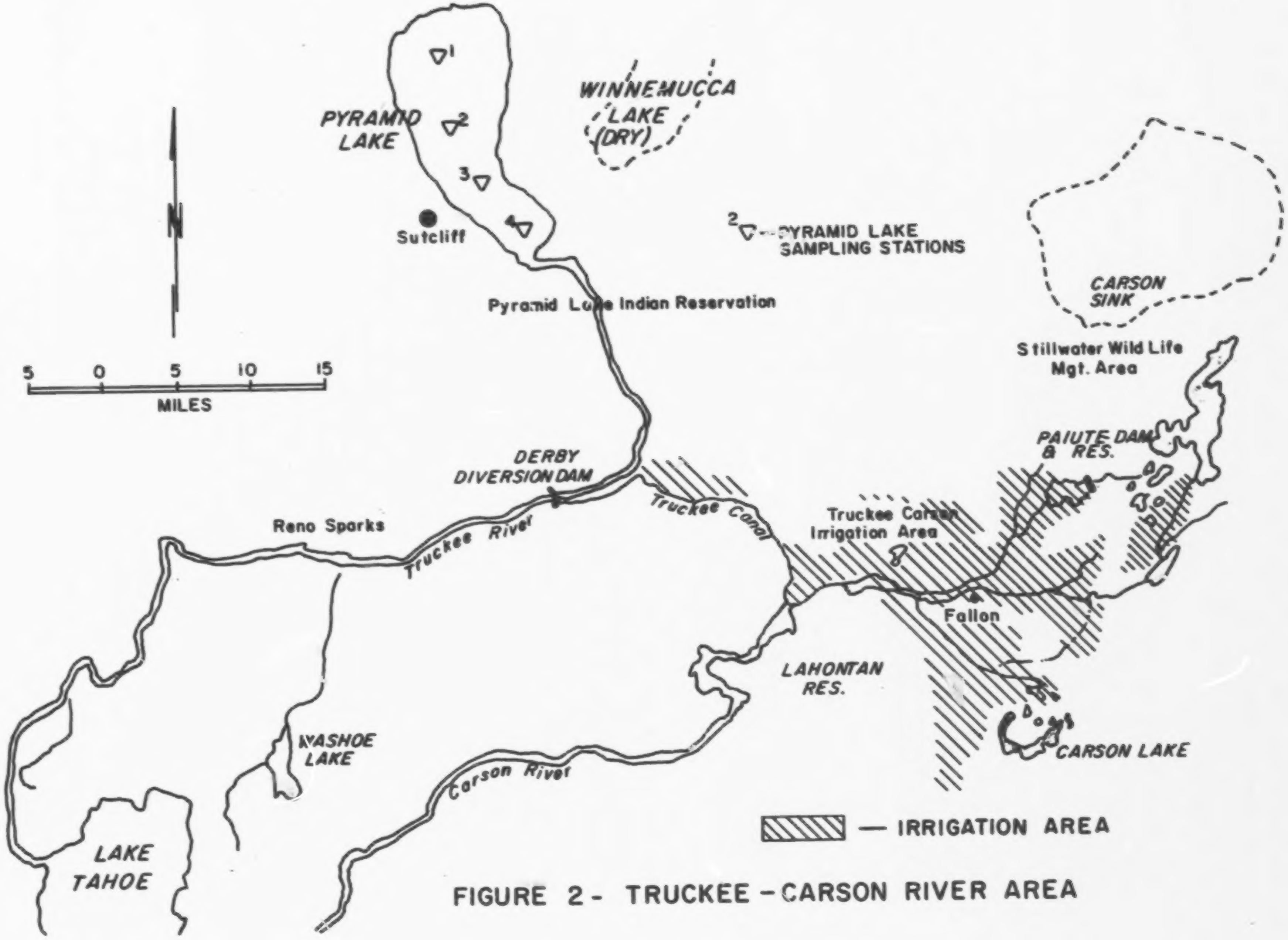

PYRAMID LAKE
1
2
3
4
Sutcliff
WINNEMUCCA LAKE (DRY)
2 — PYRAMID LAKE SAMPLING STATIONS
CARSON SINK
Stillwater Wild Life Mgt. Area
5 0 5 10 15
MILES
N
Pyramid Lake Indian Reservation
DERBY DIVERSION DAM
Reno Sparks
Truckee River
Truckee Canal
Truckee Carson Irrigation Area
PAIUTE DAM & RES.
Fallon
LAHONTAN RES.
CARSON LAKE
WASHOE LAKE
Carson River
LAKE TAHOE
— IRRIGATION AREA

FIGURE 2 - TRUCKEE - CARSON RIVER AREA

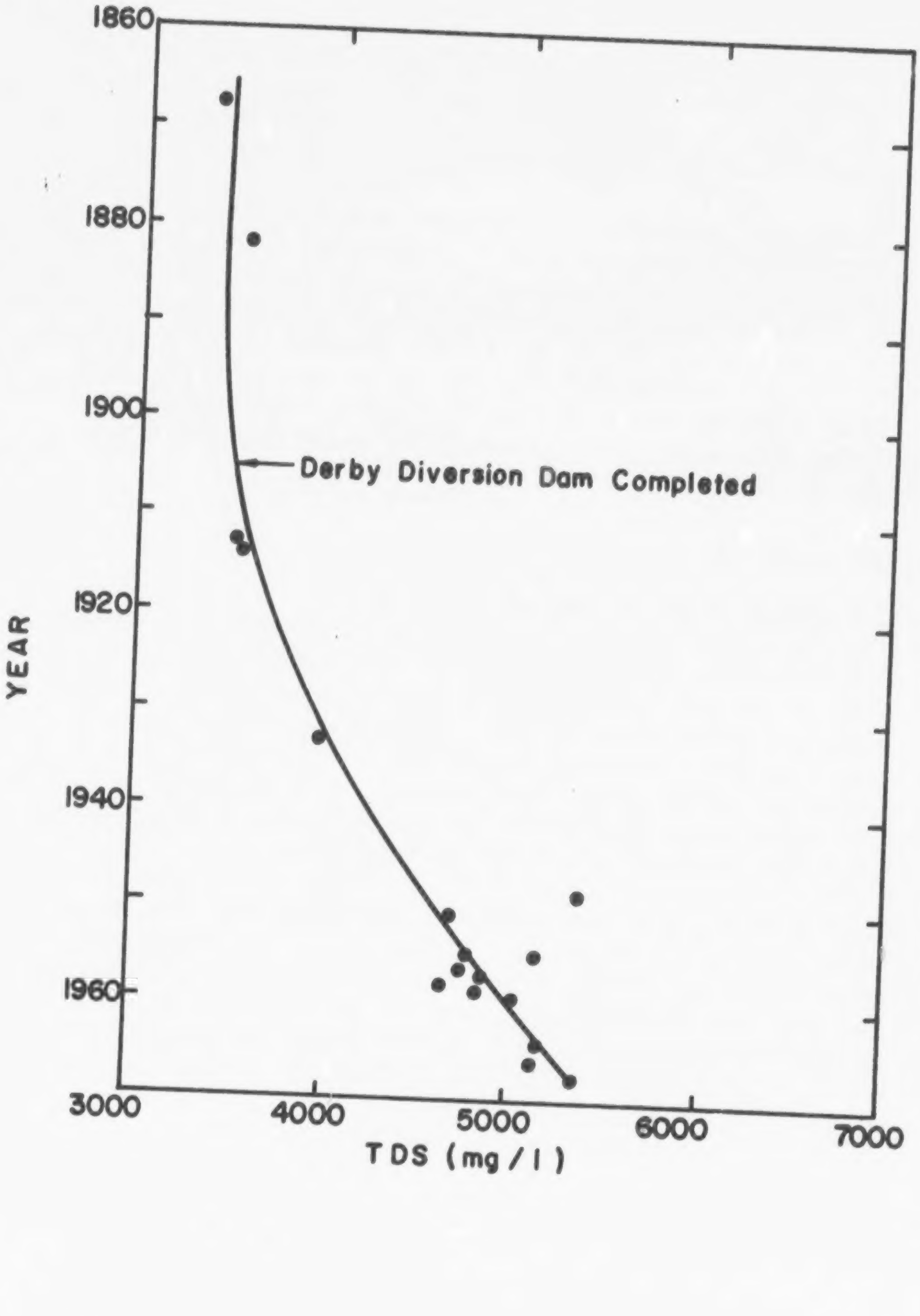


FIGURE 3 - HISTORIC TREND OF TOTAL DISSOLVED SOLIDS -- PYRAMID LAKE

physiological changes may occur with continued exposure to TDS levels above 10,000 mg/l. Trout transplanted to Eight Mile Lake, Wyoming, exhibited evidence of liver anomalies after two or three years in 12,000 to 13,000 mg/l TDS lake waters (5). Even though the fish were said to be of "good sporting quality" no assurance was given that the trout population could be maintained indefinitely at TDS concentration of 13,000 mg/l. These experiences should serve as advance warnings of the probable future effects of the imbalanced water budget of Pyramid Lake.

Other fishes of interest include the Cui-ui sucker (*Chasmistes cujus*) which is believed to occur only in Pyramid Lake. This species has adapted to the changed hydrologic regime and presently spawns in the gravels around the shore of the Lake. The Cui-ui is included on the Bureau of Sport Fisheries and Wildlife list of endangered species.

The apparent effects on the biota and desired use of the Lake have thus far been intimately connected with the physical changes caused by man rather than from the chemical or biological changes resulting from his actions. The effect of physical changes which prohibited the spawning run of the Lahontan Trout is not the only problem caused by lowered lake levels. A $500,000 park being planned for Pyramid Lake has also been affected because boat launching facilities and restroom facilities will eventually have to be moved once the Lake level has receded from them.

Pyramid Lake Water Quality

Chemical and biological changes may be more subtle. A brief water quality survey by FWPCA in the fall of 1968 was performed in order to document the present state of water quality in Pyramid Lake and provide base data from which to estimate probable future conditions. These are the only known detailed data on the hypolimnion of the Lake. Although the sampling was performed after the fall overturn had started, it is apparent that a stable stratified condition still existed. The bottom of the epilimnion was noted at about 70 feet, while the summer depth has been recorded at 20 to 25 feet (3).

Dissolved oxygen, temperature, and salinity profiles for two stations within the Lake are shown in Figure 4. These profiles demonstrate the effect of thermal stratification within the lake; organic matter which falls from the epilimnion decomposes in the deeper waters and produces the characteristic oxygen depression found in many lakes. The stratification of dissolved solids as indicated by the conductivity measurements is indicative of the large evaporative loss experienced by the Lake during the stratified period and the lack of exchange between the upper and lower portions of the Lake during stratification. The mean TDS was 5420 mg/l consisting principally of sodium, chloride and bicarbonates. TDS levels were below 3500 mg/l in 1882 and below 4000 in 1933.

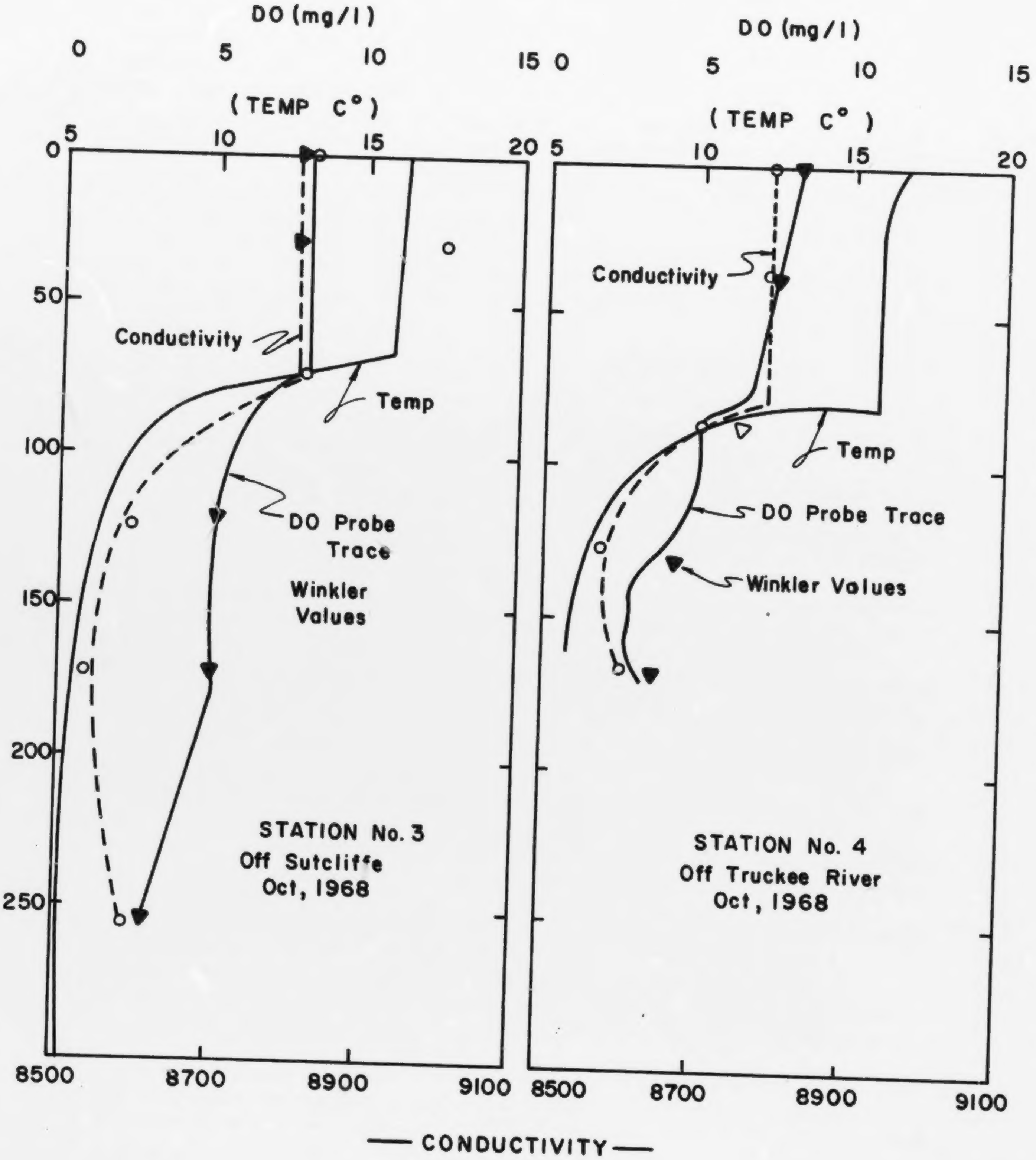


FIGURE 4 - DEPTH PROFILES OF TEMPERATURE CONDUCTIVITY & OXYGEN

PYRAMID LAKE

The concentration of the nutrients, nitrogen and phosphorus from the 1968 survey is fairly high. Total nitrogen averaged 0.58 mg/l and total phosphates (as P) averaged 0.12 mg/l. Although algal blooms have been reported to occur with regularity in the Lake, there have been no reports of conditions resulting in fish kills or other overt signs of extreme eutrophy. It is suggested that these are yet to come. In 1962, La Rivers described the Lake as "literally a culture medium for all organisms in the food chain--temperatures are warm, nutrients plentiful and fish growth rapid" (6). With the combination of present agriculture and the rapidly growing urban area around Reno and Sparks, Nevada, contributing nutrients in return waters and sewage to the Truckee River complexed with the effects of evaporation, it is certain that the future water quality of Pyramid Lake will suffer.

The Future of Pyramid Lake

Preliminary estimates indicate that continuation of existing water use practices together with projected nutrient inflows will cause the present nutrient levels to nearly triple in the next fifty years. Algal growth is expected to increase as a result of increased nutrient loadings. Increased primary productivity in Pyramid Lake is expected to supply enough biodegradable organic material to result in anoxic conditions in the hypolimnion of the Lake within the coming fifty-year period. Limnological investigations should be carried out to monitor the Lake algae, nutrient and oxygen levels. Control of nutrient discharge to the Truckee River may be necessary to arrest the rate of eutrophication of Pyramid Lake. Controls might include tertiary treatment, land disposal, or diversion of effluents to the Truckee-Carson Irrigation District.

From the time Pyramid Lake was deprived of an outlet, it was destined to eutrophy and became more saline at a faster rate since it is now the repository of all nutrients and other salts which are washed in with the tributary flow. Accepting this premise, water quality control becomes focused on means to reduce the rate at which such terminal water bodies are allowed to deteriorate.

Efforts have been made recently by the Department of the Interior to maximize flow available to Pyramid Lake while satisfying other existing water rights. A 1964 Task Force Report (7) to the Secretary of the Interior resulted in the formation of the Interior Committee on Operating Criteria and Procedures--Truckee and Carson River Basins.

Due to the efforts of the Interior Committee, the coordinated operations of the Truckee and Carson Rivers have been controlled by operating rules and regulations instituted on October 1, 1967. Additional water reaching Pyramid Lake during the first year following use of the operating rules has been estimated at between 73,000 and 125,000 AF. The operating rules and regulations are set annually to provide the flexibility to make needed changes and adjustments which would result in better use of the water resources available. Even though the current water year (1968-69) is much above normal, an additional 40,000 to 60,000 AF has reached the Lake due to basin operation under the Interior Committee operating rules this year. Thus, it is apparent that considerable progress has already been made in arresting the decline of the Lake. The Committee is optimistic that even though the water budget for the Lake has not been balanced, further progress can be made.

In its efforts to provide a solution, the Interior Committee has considered other approaches to the problem. These include the possibility of reducing the evaporative loss by artificially mixing the Lake or by the use of monomolecular films. Preliminary studies indicate neither evaporation suppression approach appears feasible; mixing indicates a theoretical water savings during summer months but heat storage is expected to increase winter evaporative losses; film methods may be prohibited by the high winds on this high desert lake. Studies by the Interior Committee are continuing toward the development of a long-range water management policy for the Truckee and Carson Rivers and Pyramid Lake.

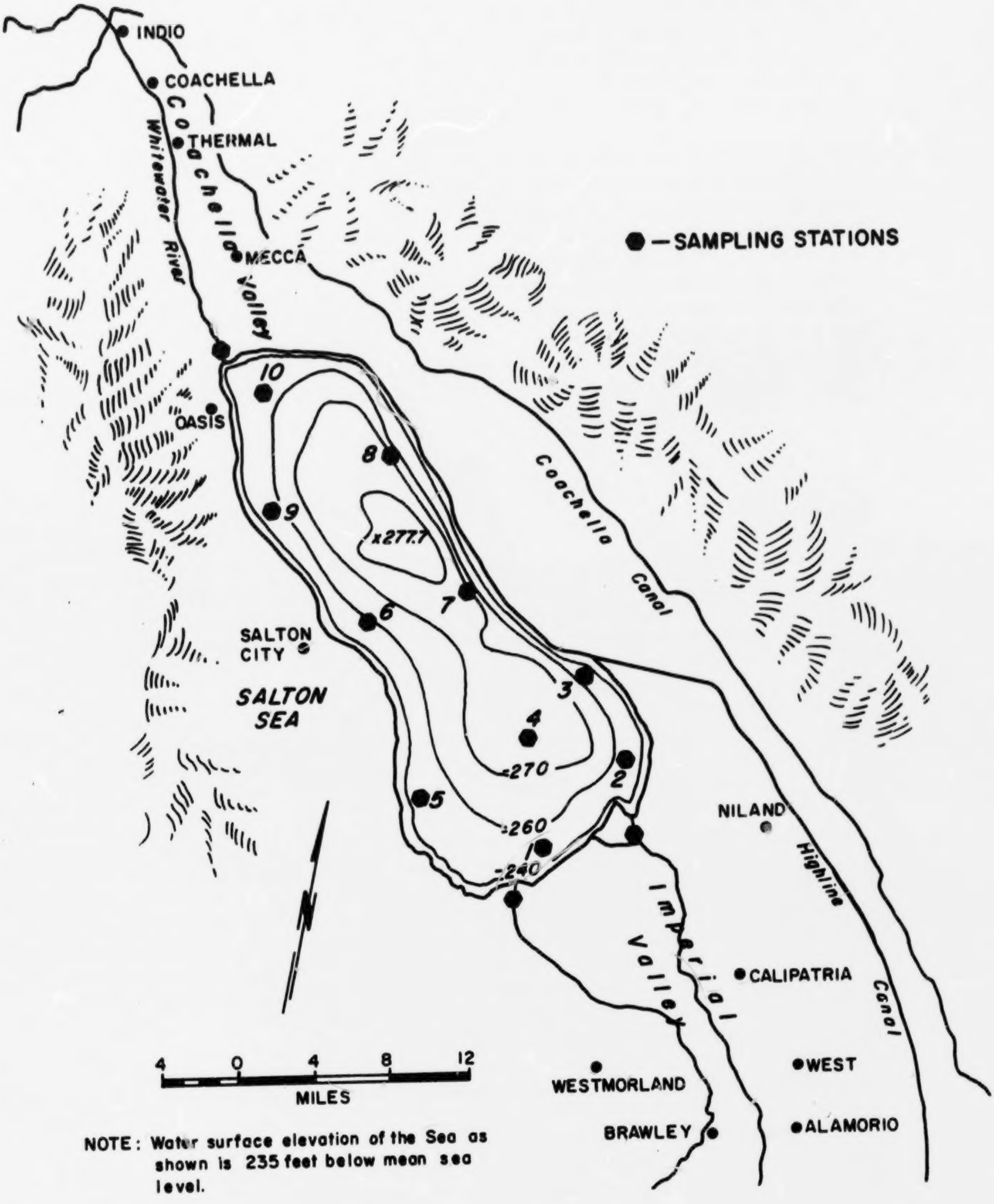
SALTON SEA

Background

The Salton Sea is an inland sink in a low-lying desert area south and east of Los Angeles, California (Figure 5). The 230,000-acre sea is threatened with rapidly rising salinity levels which, if uncontrolled, are expected to eliminate the currently valuable sport fishery within the next decade. The Sea has a volume of 6.0 million acre feet at its present water surface elevation of about 232 feet below mean sea level. Fluctuating water levels and eutrophication symptoms such as dissolved oxygen deficiencies in deeper waters, discolorations, turbidity and odors caused by dense phytoplankton populations are also major Salton Sea problems.

The Salton Sink Sea Basin, which in its lowest part is 278 feet below sea level, was the site of a large lake in Pleistocene times called Lake Cahuilla. Several geologic histories have been written on the Sink and the theories conflict regarding a possible connection with the Gulf of California. One possible explanation is that the 8360-square-mile Salton Sea Basin was cut off from the Gulf as the Colorado River extended its delta. During the last century water entered the Sink from the Colorado River on several occassions forming a small sea first discovered in 1850's. A 100,000-acre lake was formed in 1891 through a connection between the Alamo River and the Colorado River. This water evaporated rapidly and was mined for salt the following year.

The "modern" Salton Sea was formed by floods in 1905-07 which cut through a channel which carried irrigation water from the Colorado River to the Imperial Valley. The break in the channel was repaired by 1907 and since that time the Sea inflow has been controlled by


INDIO
COACHELLA
THERMAL
MECCA
Coachella Valley
Whitewater River
OASIS
SALTON CITY
SALTON SEA
Coachella Canal
● —SAMPLING STATIONS
10
8
9
x277.7
7
6
3
4
-270
2
5
-260
1
-240
NILAND
Highline Canal
Imperial Valley
CALIPATRIA
WESTMORLAND
WEST
BRAWLEY
ALAMORIO
4 0 4 8 12
MILES

NOTE: Water surface elevation of the Sea as shown is 235 feet below mean sea level.

FIGURE 5 - SALTON SEA STUDY AREA AND SAMPLING STATIONS

irrigation practice. The salinity of the Sea has increased from less than 4,000 mg/l in 1907 to about 37,000 at the present time. Salinity levels approaching ocean values have persisted for nearly 50 years while water levels were rising. Slightly higher salinities, up to 40,000 mg/l, were observed during the late 1940's due to reduced inflow. Salinity is increasing in the Sea now that water levels are more stabilized. See Figure 6 for historical salinity observations.

Published data are available on chemistry of Salton Sea waters, including a review of ionic composition from 1907 to 1955 included in the California Fish and Game Bulletin edited by Walker (8) and of 1964 sampling efforts described by Pomeroy (9). Recent data show salt levels are approximately equal to oceanic salinity although ionic composition is somewhat different. Salton Sea sulfates are approximately triple, calcium about double and chlorides 20 percent lower than typical ocean water values. Oceanic fish, barnacles, and algal species are now common in the Salton Sea.

Most of the drainage to the Salton Sea comes originally from the Colorado River near Yuma, Arizona, where waters containing about 850 mg/l salt are diverted through a series of canals westward to the Imperial Valley and Coachella Valley for irrigation use. Drainage from irrigated land collected in open field drains and subsurface tile drains is channeled to the Salton Sea. Evaporation, transpiration, and vegetative uptake of water applied to the land concentrate the salts in the moisture remaining in the field soils. The resulting drainage is often 3 to 5 times as saline as the irrigation supply and may be much higher if excess salts have accumulated in the soil. The character of this drainage usually is of a sodium-chloride-sulfate character in contrast to the sodium-calcium-sulfate supply. Of the annual 5 million acre feet imported from the Colorado River for use in the Imperial and Coachella Valleys and in Mexico about 1.2 million acre feet is returned to the Salton Sea. Evaporation losses within the Salton Sea approximate this annual inflow. Thus a hydrodynamic balance exists.

The Salton Sea currently supports a valuable sport fishery including Corvina, Sargo and Bairdiella (Croaker) which were introduced in 1948 from the Gulf of California. These oceanic species have thrived in the Sea but are not expected to tolerate salinity levels above 40,000 mg/l. Physiology studies conducted by the California Department of Fish and Game indicate survival of eggs and larvae is unlikely above that salinity. Adults may be more tolerant. Food chain organisms, of which there are very few species in the Sea, are not expected to tolerate any substantial salinity rise. The Sea is expected to pass the 40,000 mg/l level during the 1970's unless a water quality control plan is implemented. Delays will only increase the magnitude of the control developments and their cost since salt buildup, currently estimated at 5.6 million tons per year, is proceeding at such a rapid rate in the Sea.

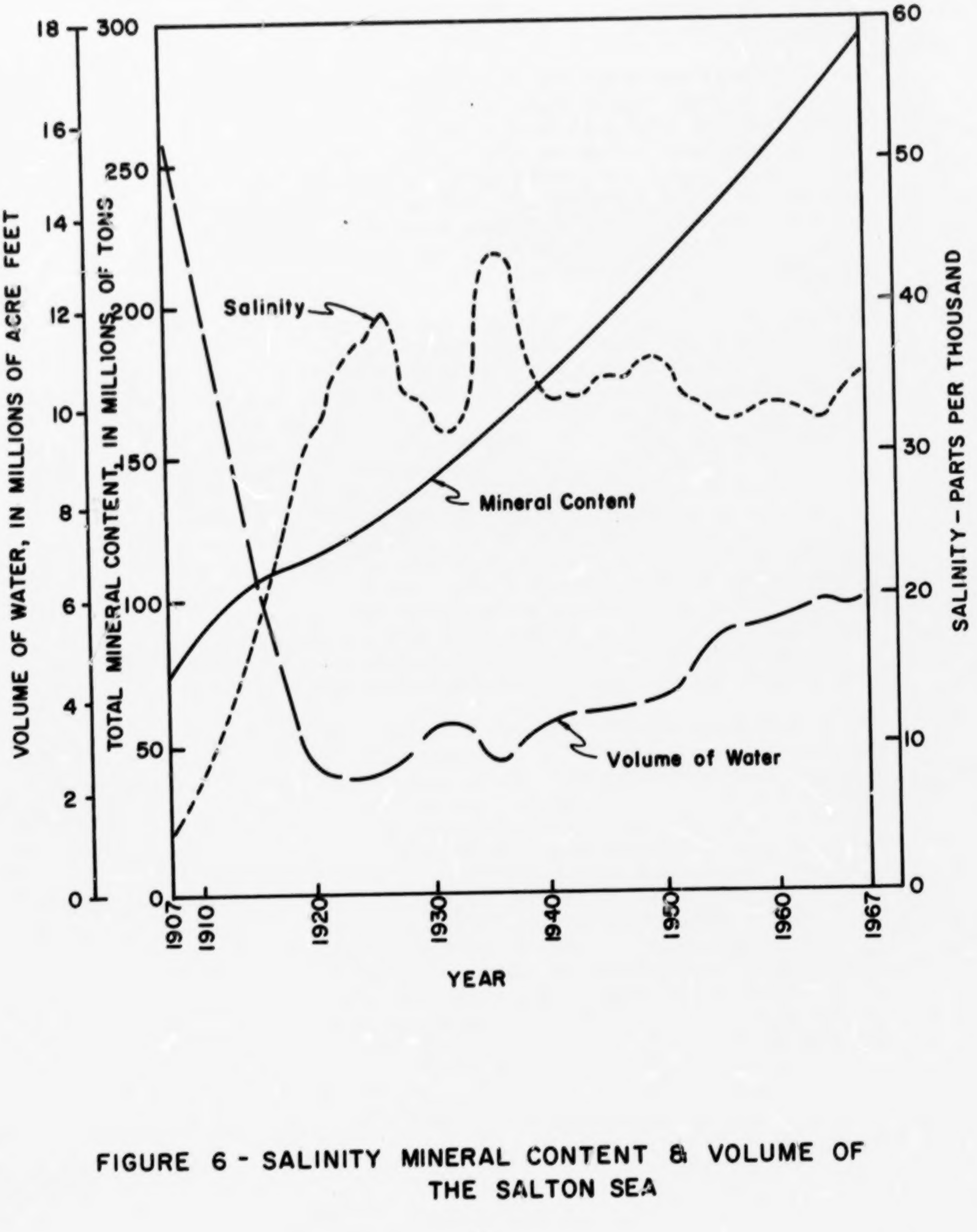


FIGURE 6 - SALINITY MINERAL CONTENT & VOLUME OF THE SALTON SEA

Water surface elevations have been generally rising in the Salton Sea basin in contrast to the falling levels described in Pyramid Lake. Rising water levels have flooded out shoreside developments and forced bulkheading and channelization projects in other areas threatened with flooding. The low angle of repose of the Sea bottom magnifies the water level problems. Drainage waters flooded the federal wildlife refuge during the 1930's, and today this area is primarily managed as a waterfowl resting area.

The Salton Sea is objectionably eutrophic and is characterized by an overabundance of mineral nutrients, mainly compounds of nitrogen and phosphorus, which produce intensive "blooms" of floating, microscopic plants (phytoplankton) in the upper levels of the water mass. Wind, wave action and currents distribute these planktonic algae throughout the Sea. The immediate visible results are discoloration and reduction of clarity of the water. In addition, although phytoplankton are essential to the ecological system of the Salton Sea, death and decomposition of large populations of these algae often result in temporary anoxic conditions, particularly in the deeper waters, and subsequent production of obnoxious odors over extensive areas of the Sea. Temporary anoxic conditions often occur in Salton Sea during the summer months, commonly leading to fish kills and the disappearance of other animals that are intermediate links in the biological food chain of the Sea. Mats of decomposing benthic blue green algae which are torn loose from the bottom occasionally form rafts of unsightly and odoriferous scum on the surface of the Sea, particularly near shore.

Eutrophication symptoms such as these were described earlier by Walker and co-workers as being prevalent in the years 1954, 1955, and 1956, the period of their study of the Sea (8). These conditions have reduced the aesthetic appeal of the Salton Sea and limited water contact recreation such as swimming although fishing activity has probably been stimulated by the productivity of the Sea.

The tributaries to the Sea carry high concentrations of nutrients originating from agricultural drainage and sewage from the Imperial Valley and from Mexico. The major tributaries averaged approximately 0.5 mg/l total phosphorus and 7 mg/l total nitrogen, primarily in the nitrate form. See Table 1 for details on nutrient content of sources. These sources discharge approximately 1 million pounds of phosphorus and 25 million pounds of nitrogen annually to the Salton Sea.

Salton Sea Water Quality

Field measurements and water samples were collected on the Salton Sea between July 1968 and May 1969. These data serve to document the present quality of the Sea, its tributaries and the nature of any water quality problems. Sampling stations are shown on Figure 5. Samples and field data collected included nutrient samples at several depths at each station, profiles of dissolved oxygen, pH, temperature

TABLE 1

NUTRIENT CONCENTRATIONS IN SALTON SEA INFLOWS

	Alamo R.	New R.	IID Direct	White-Water R.	Other CV Drains
Org.-N, mg/l	1.23	0.97	0.40	0.83	0.40
NH_3-N, mg/l	0.58	0.47	0.15	0.16	0.15
NO_2-N, mg/l	0.32	0.22	0.04	0.06	0.04
NO_3-N, mg/l	6.00*	4.48*	9.98	6.28*	9.98
O-P, mg/l	0.20	0.29	0.04	0.26	0.04
T-P, mg/l	0.29	0.53	0.06	0.53	0.06

*Includes FWPCA and DWR data

observations of color, odor, transparency, light penetration profiles, productivity measurements, chlorophyll and biological collections including both plankton and benthic life. Extensive salinity data were not collected since the mineral content of the Sea has been documented; limited mineral data gathered confirmed that Sea salinity has passed ocean values and is high in sulfate.

The mean total phosphorus and total nitrogen concentrations for the Sea during the study period were 0.07 and 3.30 mg/l respectively. Seasonal data are tabulated in Table 2. A nutrient budget of the Sea indicates that, on the average, about 45 million pounds of nitrogen and one million pounds of phosphorus are present within the Sea waters.

Nitrogen forms within the Sea are predominantly organic in contrast to the inorganically rich tributaries. Inorganic nutrients entering the Sea are converted to organic matter through photosynthetic processes. Nutrient levels in Salton Sea bottom sediments also reflect the high organic content of the sea waters. Sediment samples collected by dredge and coring devices contained about 5 percent organic carbon, 0.3 percent organic nitrogen and 0.1 percent total phosphorus.

Data from field and laboratory studies of the Sea in 1968-69 also provide further documentation as to the seriousness of fishery problems. Extensive fish kills of species such as corvina and gulf croaker were observed in the Sea near the Whitewater River inlet on two separate occasions and dead mullet were seen near the Alamo River on one occasion. Observations of dead fish were commonplace throughout the Sea. Extremely unpleasant odors were also encountered; these were especially

TABLE 2

SALTON SEA WATER QUALITY

	Summer	Autumn	Winter	Spring
NO_3-N (mg/1)	0.10	0.16	0.14	0.19
NO_2-N (mg/1)	0.01	0.06	0.02	0.30
NH_3-N (mg/1)	0.22	0.36	0.25	0.27
Org.-N (mg/1)	2.80	2.90	1.20	4.20
Total N (mg/1)	3.13	3.48	1.61	4.96
Ortho P (mg/1)	0.04	0.02	0.03	0.06
Total P (mg/1)	0.06	0.05	0.07	0.20
pH (units) *	$\frac{7.8}{7.6}$	$\frac{7.6}{7.3}$	$\frac{8.6}{8.5}$	$\frac{8.4}{8.4}$
Temperature °C *	$\frac{29.5}{28.4}$	$\frac{23.1}{22.3}$	$\frac{15.2}{14.2}$	$\frac{23.3}{22.0}$
Transparency (feet)	3.6	4.1	3.4	3.5
Euphotic Depth (ft)	--	10.4	8.5	10.0

* $\frac{\text{Surface}}{\text{Bottom}}$

prevalent near shore, often at the sites of marinas or popular fishing grounds. Strong odors, especially the rotten eggs smell characteristic of hydrogen sulfide (H_2S) were often noted and were nearly overpowering in the Whitewater River area at the time when one of the extensive fish kills was observed. A level of H_2S lethal to fish or other animals could very well have been present in the water on that occasion. High H_2S levels were also reported in May 1969.

The density of algal populations in the Salton Sea at times was so great that the water was highly discolored, varying in hue from a brick red in some areas to brown and light green in others. Examination of these water samples indicates that the brick red color was probably due to dinoflagellates, brown by diatoms or fish eggs and green by green flagellates. The Sea water was always somewhat colored and always turbid. Secchi disc readings averaged about one meter varying from about .5M to 2M; euphotic depths were approximately triple Secchi disc values.

Dissolved oxygen (DO) concentrations in the euphotic zone [2/]were invariably supersaturated during daylight hours, sometimes by a factor of 200 percent reflecting the intensive photosynthetic activity of the massive phytoplankton population.

Dissolved oxygen measurements in the Sea at depths below the euphotic zone (15 feet and below) for the months of July-November show that the DO concentration often drops to dangerously low levels, at times near zero. See Figure 7 for some representative profiles. Extensive regions of the deep water during these months often contained less than 3.5 mg/l of oxygen during daylight hours. Lower concentrations occurred at night when oxygen inputs from photosynthetic oxygenation were absent. Water temperatures varied from 29.5°C in summer to 14.2°C in winter; pH levels ranged from 7.3 to 8.8, the highest values being observed in surface waters during May.

Comparisons of organic production from other fertile waters show that maximum levels of primary production are often similar in different physical environments due to light limitations. Production of phytoplankton algae expressed as gms Carbon per square meter per day may be the same in a 100-ft. deep euphotic zone in the ocean and in a 5-foot zone in an enriched murky bay made turbid by the phytoplankton themselves. A plateau of maximum organic production is reached in highly eutrophic waters as a result of this self-limiting effect. This phenomenon is illustrated by Figure 8.

Odum has classified production rates for various ecosystems and shows maximum values of 1.0 gram of carbon fixed per square meter per day for oligotrophic (nutrient poor) lakes and oceanic areas (10).

[2/] The euphotic zone is often defined by the depth which sunlight sufficient for photosynthesis occurs--often this is approximated by the depth at which light energy equals 1 percent of surface light intensity.

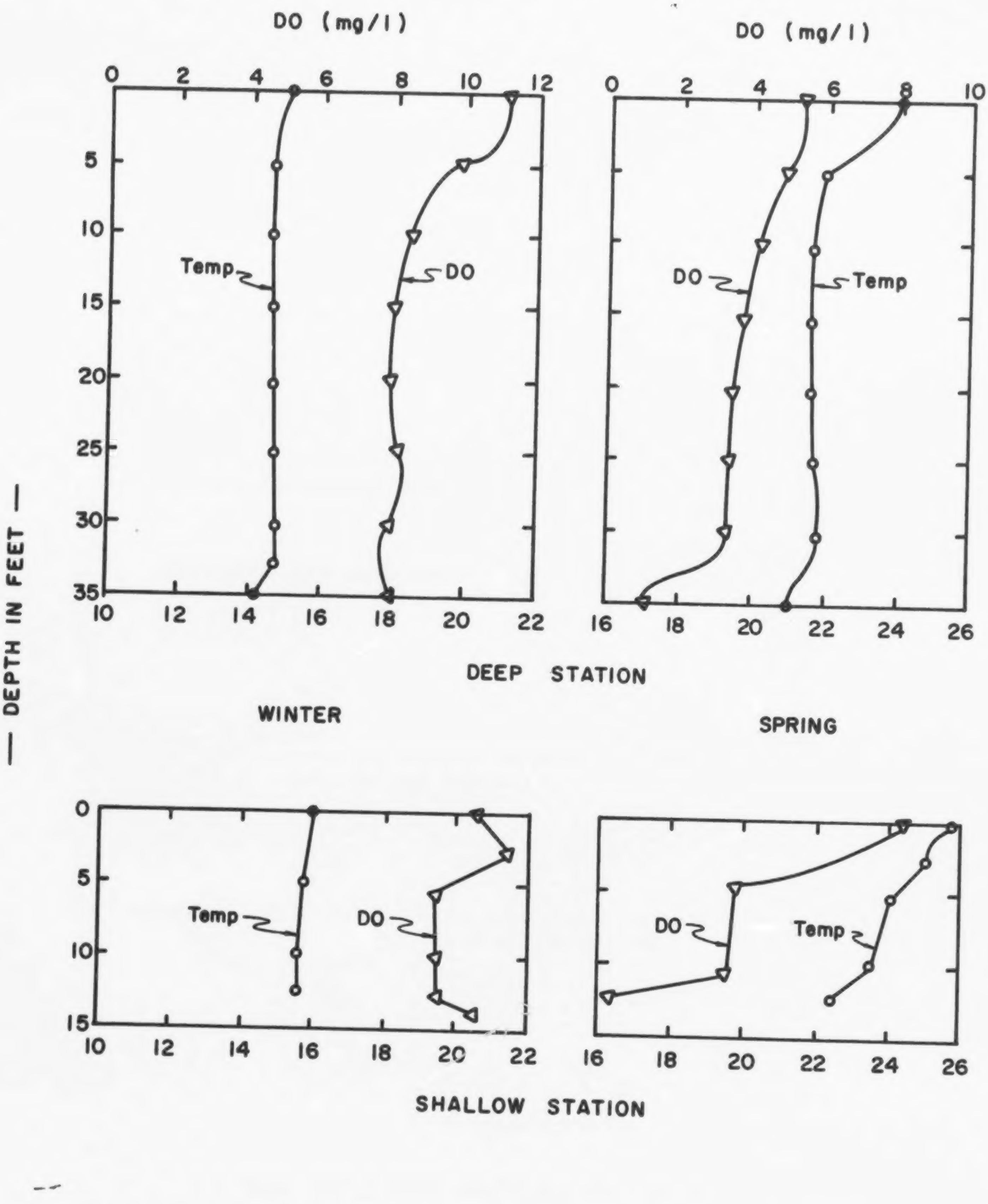
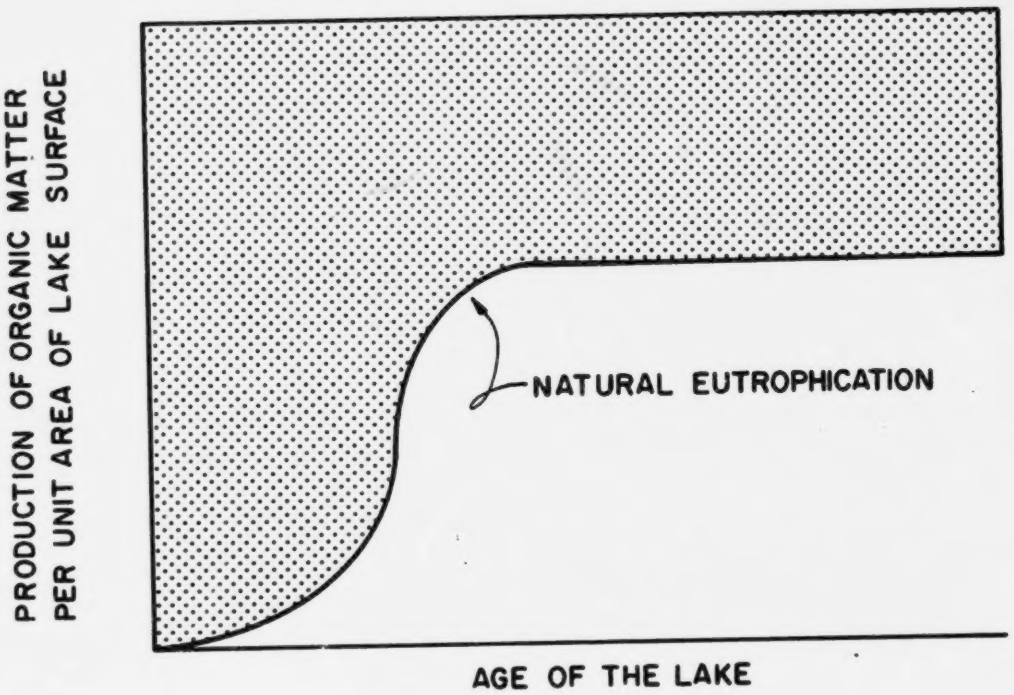


FIGURE 7 - DEPTH PROFILES OF TEMPERATURE & OXYGEN
SALTON SEA



Note: Adapted from Hasler, A.D. Eutrophication of Lakes by Domestic Drainage, Ecol 28(4) 1947

FIGURE 8 - PRODUCTION AND LAKE AGE -- SALTON SEA STUDY

Shallow, eutrophic lakes are expected to produce up to 5 gms C/m^2 day; values over 3 gms $C/m^2/day$ in aquatic systems are considered high. Measurements of primary production in the Salton Sea during 1968 averaged about 3.0 $gmC/m^2/day$ and exceeded 5 $gmC/m^2/day$, on several occasions. These high productivity values are in the range expected in the shallow, nutrient rich Salton Sea.

The Future of the Salton Sea

A salinity control plan is undergoing study by agencies of the Department of Interior and the State of California. A reconnaisance Report, to be published by the Bureau of Reclamation in 1969 will outline alternative salinity control plans. Earlier studies by Pomeroy considered the use of large evaporation ponds formed by diked areas within the Sea (10). Such a scheme provides a salt outlet through salt extraction from solar evaporation, thus stabilizing the salinity of the Sea. If such a method were employed,the resulting salinity level of the Sea would depend on pond size and the timing of such a project.

The nutrient content of the Sea is not greatly different from the computed annual inflow; yet comparable annual loads of nutrients have been entering the Sea for decades. Soluble forms such as NO_3 have not built up in the Sea over the past decades, but rather have been converted to phytoplankton in the warm, shallow sea later to be deposited as dead organic matter on the sea bottom or consumed by predators within the sea. An equilibrium is maintained wherein entering nutrients are assimilated by the Sea's ecological system or deposited into the rich bottom sediments. Only a relatively small fraction of the nutrients which have entered the Sea over the years are maintained in the water phase.

Fish harvests, although sizeable, cannot account for these major changes in nutrient level; for example, annual harvest of 100 lbs. of fish per acre would remove slightly more than one half million pounds of nitrogen or about 2 percent of the annual nitrogen load (based on 2.5 percent nitrogen in fish flesh by wet weight). The estimated Salton Sea harvest rate was about six pounds per acre in 1966.

In summary, the nutrient related problems of the Salton Sea are those expected in highly eutrophic waters. The enrichment of the water phase is probably as advanced as is likely in this inland sink where nutrient trapping and the dynamics of the eutrophic ecosystem have subdued the fertilizing effects of the rich tributaries. While salinity increase is the most pressing water quality problem and a task force comprising agencies of the State of California and the Department of Interior is evaluating salinity control plans, work is also in progress on plans for water level stabilization, nutrient control and ecological protection for the Salton Sea.

SUMMARY

The problems of Pyramid Lake, Nevada, and Salton Sea, California, are similar in many ways and are common to other inland sinks. Salinity increases and water level fluctuations attributable to water and salt inflows and evaporation losses may be controlled or abated through river basin and water quality management schemes. Pyramid Lake water levels and the rate of salinity increases can be controlled by increasing the water supply to the Lake. Salton Sea salinity and water level problems can be better controlled by salt extraction, lower irrigation efficiencies in nearby agricultural areas, bulkheading on developed parts of the shore, and possible future evaporation pond operation. Eutrophication symptoms, advanced in the Salton Sea and emerging in Pyramid Lake, are less easily manipulated. Natural forces of deposition and consumption of organic matter within these waters will tend to limit nutrient buildup; however trapping and predation effects alone will not eliminate algal blooms. Control of eutrophication must begin with control or elimination of major nutrient sources.

Although the quality of both the water bodies discussed is far from "pristine," nonetheless both are economically valuable water resources. The future of either is uncertain; however, it is clear that unless water quality control measures are taken, both will eventually become aqueous deserts. The problems of these two desert lakes are recognized both locally and nationally. Local, State and Federal efforts are underway to preserve or enhance the water quality and associated uses of these two inland sinks.

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NATURAL POLLUTION IN ARID LAND WATERS

by

John M. Neuhold [1]

If pollution is a degradation of the environment as a result of man's activity in it, and if man is considered to be apart from the natural environment, then the terms natural and pollution are clearly contradictory. In this paper I explore the meaning of natural pollution as it might apply to an arid lands water system, generalize a definition for this pollution and speculate on the possible consequences of the pollution thus defined. The water system we will consider will be limited to the surface waters in arid lands, since these waters most obviously reflect the effects of the meteorological contribution from the hydrological cycle.

Characteristics of Arid Land Waters

Arid lands are characterized by a precipitation-evapotranspiration ratio that favors evaporation. Under these circumstances, shallow, standing bodies of water with a large surface area are not favored except in endorheic basins where the input of surface water from the watershed is at equilibrium with evaporation from the surface of the basin. Such a permanent body of water is essentially a function of the size of the watershed and characteristics of the catchment basin.

Aside from permanent bodies of water in endorheic basins, surface water in arid lands exists primarily as streams or rivers. The watersheds are chacterized by shallow soil development and low vegetative cover, a situation that favors substantial surface runoff. Sustained flow in water courses in arid regions is the result of melting snow packs at higher elevations or of sub-surface water flows in deep alu or deeper aquifers. Because of the high degree of surface runoff when precipitation does occur, waterflows in the streams are marked by violent fluctuations in volume. In the higher order streams, they can range from nothing to floods, and in the lower order, sustained-flow streams it can range from low, clear flows to high, turbid flows.

Because of their relatively low mechanical stability, soils in arid lands are highly susceptible to erosion. During periods of precipitation, therefore, the surface flow is usually loaded with relatively high concentrations of particulate matter which in turn increases the corrosive quality of the water, and its turbidity. High evaporative losses result in a concentration of solids dissolved from the geological formations making up the watershed and the silt loads carried by the runoff. In general, the sustained water flows in arid lands are

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characterized by violent fluctuations in water level, high turbidities, and a relatively high proportion of dissolved solids. Down stream, salt concentrations and water temperatures are increased while fluctuations in silt loads and waterflows are modulated.

An ecologist cannot discuss any aquatic system without also mentioning its biological system. Every environment in the earth's biosphere has a life system of one form or another developed in it. Waters in arid lands are no exception. The remarkable thing about the life systems in arid land streams are their adaptive qualities. Not only is each life system geared to the violent changes in quality, but the individuals making up that system are morphologically adapted to sustain themselves under these violent changes. Fish, for example, are morphologically adapted to cope with torrential flows and corrosive silt loads. They are also physiologically adapted to handle sudden changes in temperature and salt concentration.

Aquatic insects, the predominant herbivores in the system, are likewise adapted morphologically and physiologically with timed stages of their life cycle to "fit" the demands of the system. The primary producers of the system, the algaes and diatoms, are perhaps most susceptible to changes which occur. The scouring action of silt-laden waters makes life for the primary producers somewhat tenuous. Although it is not unreasonable to assume that a significant amount of primary production does occur in these waters, it is also likely that terrestrial sources supply quantities of organic materials via the surface runoff. In any case, biological systems are important in arid land waters, particularly relative to pollution, since it is the biological system that first shows signs of the effects of that pollution. The aquatic system thus is characterized by a specifically adapted biological system that is a living, cycling pool of organic matter and nutrients, and may serve as an indicator of pollution.

Uses of Arid Land Waters

Because of the scarcity in arid lands, water is much sought-after for both consumptive and non-consumptive uses. Predominant uses include irrigation, power generation, stock watering, community, industrial, recreation, and navigation. Each of these uses has a unique set of water-quality requirements. Those irrigating crops and watering stock, for example, are concerned with the type and quantity of salts. Power generation and navigation usage require certain flow regimens. Culinary and industrial use must consider the economics of treatment.

Pollution Defined

The subject of this discussion is natural pollution in arid land waters. Pollution is variously defined depending upon man's use or nonuse of the water. But most definitions agree that pollution implies a change in quality as a result of man's use. Similarly, the term natural can be variously defined. It can include or exclude the influence of man.

The "I - Thou" Definition of Pollution

Since man is an inextricable part of the biosphere and must be incorporated into any consideration of ecosystem dynamics, I prefer to look upon natural pollution as including his effects. However, since he is rational and in potential control over his actions, his effect in the natural system must be given a set of continuously variable values dependent upon the state of his technological development. The *most* natural system, then, would include man in a hunter-gather culture, whereas the *least* natural system would have him in a high state of technological development.

Most conservationists would treat the natural environment as a discontinuous variable. Under their interpretation, natural pollution could only be contributed by catastrophic geomorphic and meteorological events. The only criterion for measuring that pollution would be a change in the precatastrophe ecological system. Such events could include volcanic activity, sudden and abrupt faulting resulting in changes in water courses and sudden and abrupt changes in weather patterns. Man's role in the environment defined as *most* natural is relatively minor. He serves as a top carnivore with a limit to population size dependent upon the production of the land area.

Development toward an agrarian-herdsman culture results in an increasingly intensive use of land by man, with concomitantly increasing effects upon the waters of that region. More use of the watershed by grazing animals under man's control, and his development of cultivation and irrigation practices increase erosion probabilities and thus the silt loads of the streams. Irrigation increases the total dissolved solids in the waters returned to the natural system. In addition, human populations densely congregated and their associated effluents become more of a factor in the ecosystem.

If we follow the development of man into an industrial culture, we find additional uses of the lands including extraction of mineral resources from the watersheds, intensification of man's activities on those watersheds, and more conditions conducive to changes in the quality of water in the area.

At the existing state of technological development, man's use of an ecosystem becomes more pervasive through the adding of contaminants to the atmosphere, which in turn are precipitated upon watersheds and contribute qualities to that watershed previously not present. These eventually are reflected in the stream collecting systems. For example, consider chlorinated hydrocarbons, which though used primarily in areas quite remote from arid lands, can find their way through meteorological sources onto the watersheds and eventually into the streams.

As I am defining natural pollution, it is a function of the state of technological development of the human population on earth. Man is part of the system. Taking Martin Buber's words, man is the "I" and the environment is the "Thou." Note that pollution is considered to be whatever is added to the water that causes a change in the ecological system developed there. This definition admits man into the system and allows for the development of a naturalistic ethic that man is fully capable of imposing upon himself. In other words, as an ethic is developed, the effect of technology may be reduced and the ecosystem becomes the true criterion for pollution identification.

The "I - It" Definition of Pollution

If any ethic has developed however, it is founded on the egocentric viewpoint of material gains from watershed and water (man is the "I" and the environment is the "It"). Thus our definition of pollution must incorporate the use-oriented value system. In other words, water can or cannot be polluted relative to the use to which it is put and not relative to the system (including man) that has developed under most natural conditions. Therefore, if arable lands are available at the terminal ends of arid land systems, but the water arriving there is too salty for irrigation use, the water is polluted in relation to that potential use. Or the water is polluted when it is too silty for industrial use even if the water at that point in space and time had received its salt and silt loads in a "natural" way.

In this context, "natural" is considered to be any influence on water quality not caused by man. Salty water from springs, silt from pristine watershed, wildlife fecal contributions are examples of "natural pollution." The problem with this definition of natural is that natural salt springs contribute insignificant amounts of salt to the surface water, pristine areas no longer exist and no population of wildlife has escaped the influence of man. For example, some duck populations around the Great Salt Lake are several magnitudes greater in numbers now as a result of marsh management and agriculture, than they were in early pioneer days. Certainly, the nitrogen input into the marshes via duck droppings has also been increased.

Conclusions

There is virtually no arid land in this world that does not support some form of man's activity. Certainly irrigation technology has been widely applied to arable lands. Stock raising predominates over great portions of arid and semi-arid watersheds. Many of the arid lands are also rich in minerals and other geological deposits of value to man, and therefore mined. Man's activities in arid lands require road construction; therefore, surface disturbance results. Power generation requires the construction of dams on the rivers and these change the quality of the water below the dam as well as above. In the context of our first definition of natural systems, these activities produce a semi-natural type of pollution that nonetheless falls into the category of natural.

Despite technological development, arid lands in North America are still sparsely populated. Intensive agriculture and industry and urban settlement involve only small portions of the total arid land use. However, whatever water is present in such areas is sure to be polluted regardless of the definition used. Any additional use of an arid land watershed produces materials sufficiently different from that which would have occurred under the existing use to qualify as pollution.

From geological sources, one can expect increased concentrations of salts of various types, including the heavy metals and increased turbities. Mining activity brings minerals to the surface that eventually may find their way into the stream courses and cause considerable damage by producing toxic concentrations of elements that are deleterious to the ecological system. Certainly this occurs when mined minerals are upgraded and the liquors of the upgrading process are released to the stream courses. Meteorological sources will bring, in addition to the precipitation, airborne pesticides and other organic and inorganic effluents of industrialization, some of which may be in sufficient quantity to be toxic to components of the aquatic ecosystem. Grazing activities tend to reduce plant cover, and if not managed properly can denude the watershed resulting in increased erosion and subsequently increased silt loads. Intensive concentrations of grazing animals near watersheds produce quantities of organic nitrogen compounds. Irrigation use of water results in increased salt concentrations of the returned effluents. The lower Colorado River provides a good example of such phenomena. All these contributions to the aquatic system affect the "naturally" evolved ecological system. At the same time, they also affect other uses of the waters downstream.

Dams constructed on the main streams of arid lands have done a great deal to reduce turbidities and regulate flows. The effects produced on the ecosystem in the forbays and on water quality for long stretches downstream from the dams have been great. The existing ecological systems of these streams were essentially wiped out and other systems replaced them. Further, the dams have allowed the lands under their influence to accommodate greater numbers of people. Greater numbers of people, in turn, contribute more effluents to their environment. The net result has been that the streams must bear the effluents from that increased population, which affects the area's newly developed ecological system, man included.

The distinction between our original two definitions are important. In the first, man is considered part of an ecosystem which he can manipulate but only to the limit of available resources or to levels of limiting factors before collapse of the system results. As Marston Bates points out, man is part of a continuous and interrelated network of life that makes him as natural as an algae. What affects the system affects him. In the second definition, man sets himself apart from the system. He manipulates it to maximize his immediate economic gain. In the first, an ecological ethic of land and water use is inherent. In the second, it is nonexistent.

The ramjet process of people begetting development begetting people is limited in arid lands by the availability of water. Unless an ecological ethic is developed and implemented by man for the use of these waters and the associated land areas, man may find himself to be the factor limiting his own existence.

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DISTILLATION OF WASTEWATERS: A WATER RESOURCE FOR ARID REGIONS

by

Allen Cywin, George Rey, Stanley Dea, and Harold Bernard [1]

The use of distillation as a means of producing high quality water in arid regions has previously been limited to applications using saline waters as a feedwater supply, either from brackish ground water or the ocean. Another potential source of distillation feedwater in arid regions which should not be overlooked and may be useable for distillation processes is the wastewater effluent from secondary municipal sewage treatment plants.

Conceptual arrangements of how distillation may be used in wastewater renovation schemes center about the concept of wastewater recycle. Typical systems have been outlined by Hickman (1) and Stephan (2). Both systems are based on recycling for potable water reuse, some or all the municipal effluent from biological secondary treatment plants. These proposed systems are still conceptual, and remain to be demonstrated. The system proposed by Stephan is shown in Figure 1. Here distillation is used in a split flow manner in order to provide the salt removal capability required for continuous water recycle for potable reuse. In this plan pretreatment requirements before distillation were not identified in detail.

An alternate to the potable water reuse plan by recycle would be the production of low mineral content water for industrial purposes, particularly for those industries which require such water in large quantities. The scarcity of low mineral content water in many of our arid regions currently requires high treatment costs for the water sources available, if such treatment is not applied excessive maintenance costs for machinery, boilers, piping, etc. are incurred.

A review of past studies (3,4) suggests that with the proper development of a municipal secondary effluent conditioning process, this source of water may be suitable for use as distillation process feedwater. This very possibly results in less costly distilled water as compared to the costs of conventional distillation processes using saline water sources as feedwater. In addition, a part of wastewater renovation costs can realistically be attributed to pollution control requirements. This is particularly true in areas where tertiary treatment of effluents may be necessary to meet water quality standards.

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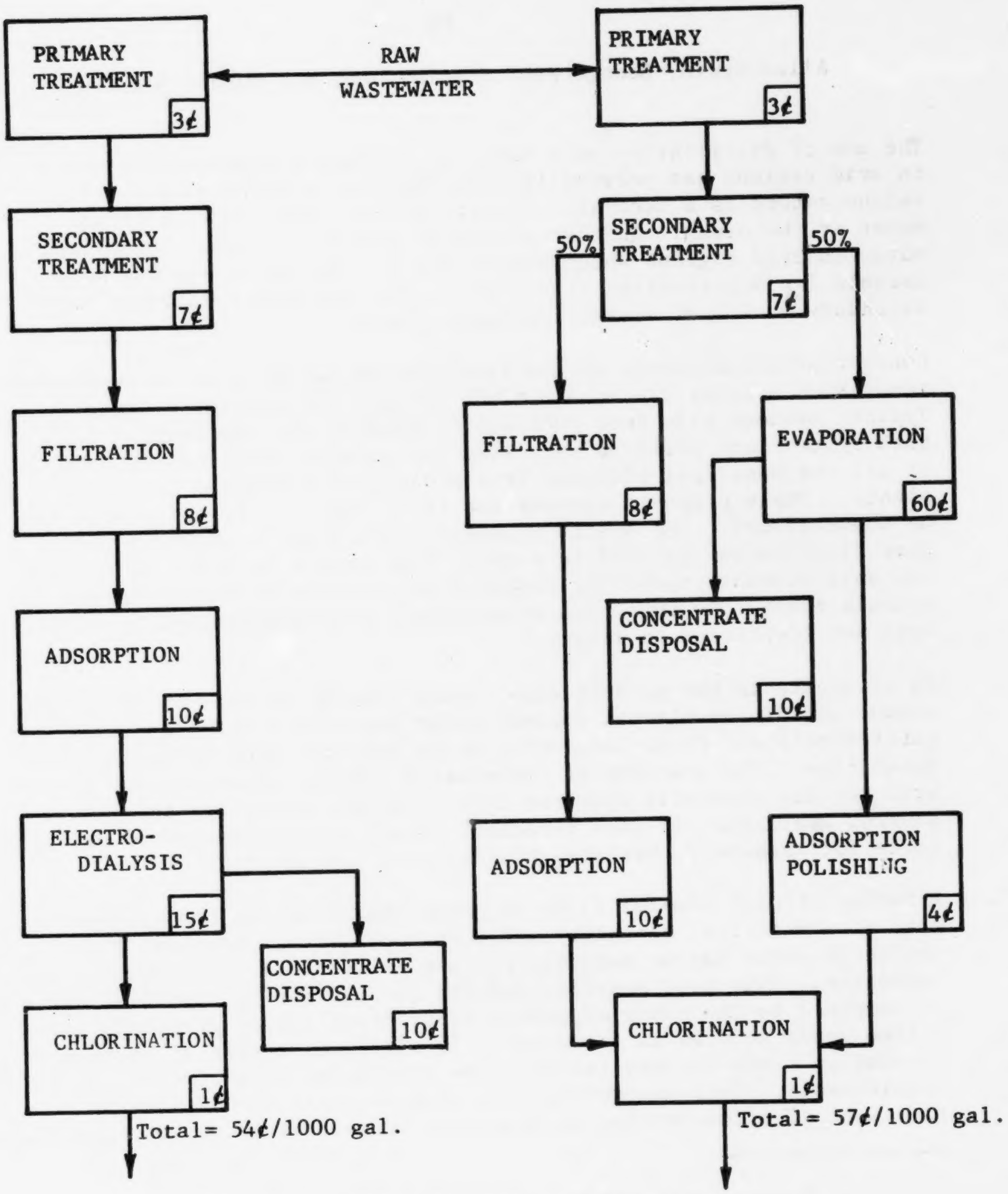

PRIMARY TREATMENT 3¢
RAW WASTEWATER
PRIMARY TREATMENT 3¢
SECONDARY TREATMENT 7¢
SECONDARY TREATMENT 7¢
50%
50%
FILTRATION 8¢
FILTRATION 8¢
EVAPORATION 60¢
CONCENTRATE DISPOSAL 10¢
ADSORPTION 10¢
ELECTRO-DIALYSIS 15¢
ADSORPTION 10¢
ADSORPTION POLISHING 4¢
CONCENTRATE DISPOSAL 10¢
CHLORINATION 1¢
CHLORINATION 1¢
Total= 54¢/1000 gal.
Total= 57¢/1000 gal.

Figure 1 - Water Renovation Scheme

It is felt that for the immediate future, industrial reuse of municipal effluents will take precedence over potable water reuse. This is particularly true in view of the water needs for industry as forecast (5,6). In addition, reuse for industrial purposes would have less stringent health and safety requirements to meet.

Considerations

Renovating municipal effluents to meet the chemical requirements of potable water standards can be accomplished by using tertiary treatment processes for the removal of the remaining organic, ammonia, and mineral constituents. In some cases the use of a demineralization step may even be avoided by blending tertiary-treated effluents with a lower mineral content municipal water intake. This approach was outlined by Hickman (1) and can produce a product water of acceptable mineral content in some cases. Such a method effectively reduces the mineral content of recycled water by dilution.

In addition to the possibility of renovating effluents for potable use, consideration should be given to renovating effluents for use as an industrial water supply where a dissolved mineral content of 50 ppm or less is desired. It should be realized that the cost of demineralizing effluents may well be competitive with the cost of desalting brackish or saline supplies by the use of distillation. In fact, a study by Gerster (7), indicated lower costs may be possible if the maximum operating temperature could be raised to 350° F.

Research on the problems and costs of using effluents have been undertaken by the Federal Water Pollution Control Administration (FWPCA). However, more development work, and engineering demonstrations are necessary in order to give potential users the necessary assurances needed to implement effluent wastewater recycle or reuse for producing high quality water.

An important consideration for the attractiveness of municipal effluents as distillation feedwater relates to the sulfate content. Table I presents average sulfate concentrations for various types of potential feedwater supplies in arid regions. It shows that wastewater effluents are considerably lower in sulfate content than either ocean or brackish waters.

The lower concentrations of sulfate and total dissolved solids in wastewater effluents will permit less percentage blowdown in a distillation system than with most natural brackish waters and far less blowdown than with seawater. The net results will be more product water and heat conservation. Approximately 25% of the feed in ocean water must be used for blowdown versus an estimated 5% for waste effluents because of lower sulfate and solids contents. Lower sulfate contents of wastewater should also allow higher operating temperatures to be used for evaporation, less extensive sulfate scaling, and consequently lower potential cost of distillation per unit of water distilled.

TABLE I

SULFATE CONTENT OF WATERS

Source	Approximate Concentration, mg/l
Ocean	2700
Los Angeles - San Diego, Calif. (Wastewater Effluent)	300
Tucson - Phoenix, Arizona (Wastewater Effluent)	150 - 300
Buckeye, Arizona (Brackish Supply)	50 - 1500

Stephan's prior prediction (2) on the role of wastewater effluents for reuse indicates that the highest cost of renovating effluents for use in a water recycle plan is related to the demineralization operation. If we were to assume a hypothetical secondary effluent wastewater with a mineral content (TDS) of 850 ppm (City of San Diego, half of South Dakota, etc.) and we require a water of 50 ppm or less (therefore a removal of greater than 800 ppm), it is our estimate at this time that distillation of wastewater could, for large scale use, be economical, competetive or even advantageous in comparison with other sources of supply.

Using a 10-20 MGD demineralization capacity as a study case, the total cost of distilled water production is estimated to be about thirty-six cents per thousand gallons of effluent used. The cost includes our best estimate of pre- and post-demineralization treatment requirements. On the basis of this estimate, it appears the distillation process should be considered for wastewater renovation to produce industrial waters requiring less than 50 ppm of dissolved mineral content. In contrast, electrodialysis (ED), another method of demineralizing wastewater, would be limited to producing water of about 300 - 500 ppm when used in an optimum manner (8).

In light of recent advances in thin-film distillation technology (9), even further cost reductions may be possible. Particularly if long tube vertical (LTV) distillation is utilized. For this type of plant the blowdown ratio should be about 5% of the total flow when distilling many municipal effluents. The recent development in higher heat transfer coefficients for falling thin-film evaporative surfaces is comparable to increasing the permeability of existing membrane demineralizing systems (ED or RO) by a factor of 3 to 4, with no additional increase in power consumption or transfer area. It should be realized that this relatively simple development took some eight years to become a reality in spite of the fact that it was known to be theoretically possible for years prior to initiation of development work.

Also, to be given consideration is the quality of the distilled water in terms of total dissolved mineral solids (TDS) content. It generally is too good to blend into a lower mineral grade water supply, particularly when low mineral content water is expensive to make and processes for making it result in additional cost appreciably above the initial supply used (assuming municipal water supply). A further consideration is that the projected demand for lower mineral content water is increasing considerably (10).

If a distillation-dehydration process (11) were to be used for treatment of municipal sewage sludges, 0.5% of the total plant wastewater influent could be recovered as a by-product distillate water. In such a process the heat required for distillation would be obtained by incineration of the dehydrated sludge. This example implies municipal sewage wastewater has sufficient recoverable heat values to provide some of the energy necessary to purify the per capita water consumption demand.

Our survey of sewage and refuse heat values coincides with those of Burns and Roe (12) in which the heat values in municipal wastes (both solid and liquid) on a per capita basis was found to be sufficient to distill 25% of the total per capita water demand. The energy involved is nearly (approximately 75%) enough to demineralize the per capita wastewater effluent from 850 to 550 ppm using distillation in a split flow water reuse plan (Figure 1).

Research and Development Requirements

In view of the considerations presented and initial studies (3,4,7,13) on the application of distillation to wastewater renovation, R&D work with distillation processes, as applied to wastewater renovation, should be continued. The work of O'Conner (4) is encouraging, and the problems of ammonia and volatile organics identified in the study may hopefully be resolved by further laboratory and pilot plant work. In view of the potential for obtaining higher heat fluxes in the use of LTV distillation vs. the multiple stage flash (MSF) system, pilot plant or demonstration efforts emphasizing the use and further development of LTV distillation systems is recommended. Particular attention however, will need to be devoted to the feedwater pretreatment requirements and operating conditions for the first stage effect. Pretreatment systems generally include deaeration - decarbonation devices, and in some cases, as for boiler water preparation, include hot lime softening within the deaeration operation. Thus, developing the pretreatment system to provide for multiple functions and increased effectiveness for organic and ammonia removal should be possible.

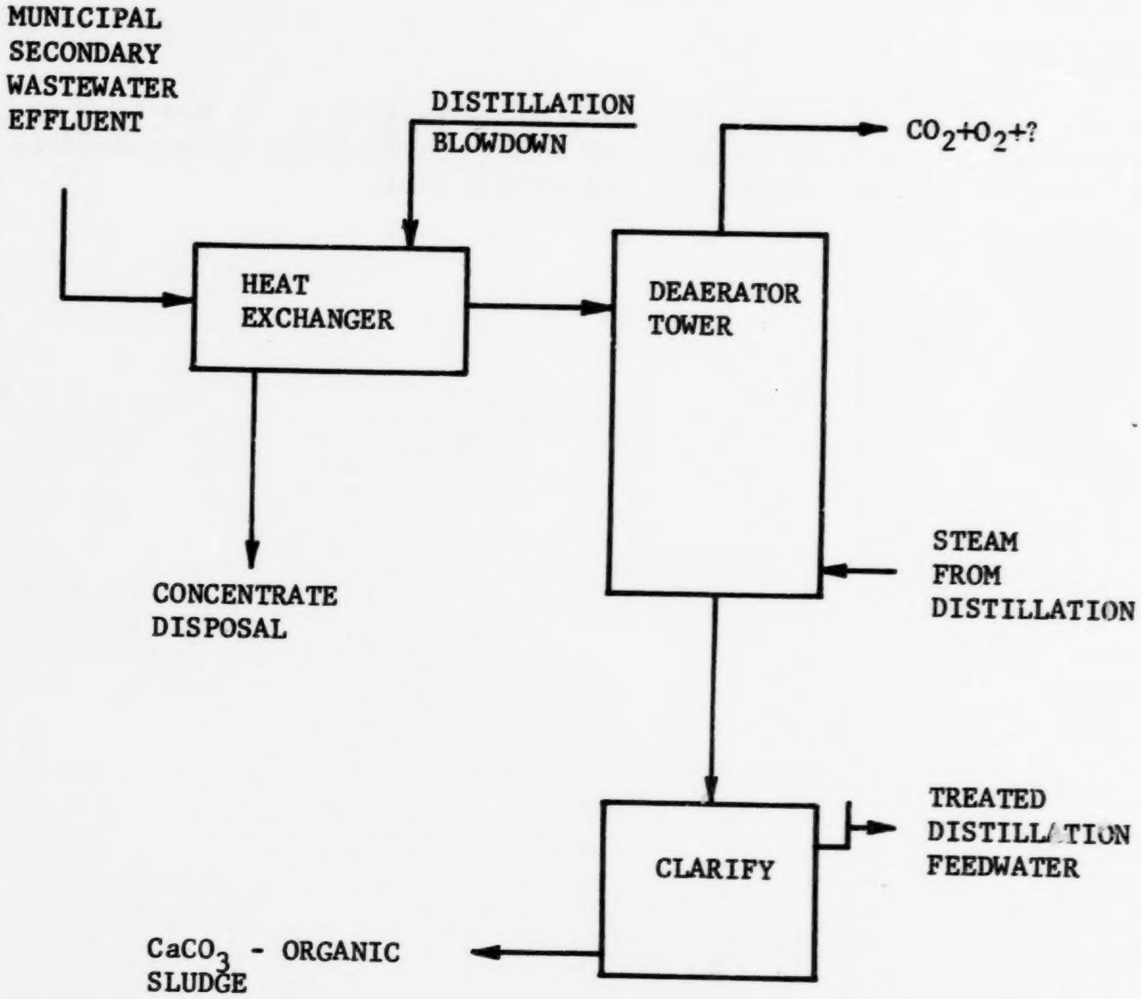
For example, as shown in Figure 2, a countercurrent steam stripping deaerator could result in producing the same chemical effects as the "hot" lime process and thus precipitate temporary calcium hardness as calcium carbonate while stripping carbon dioxide, oxygen, and volatile organics. The carbonate precipitation naturally softens the water but also can be expected to coagulate and remove suspended and possibly dissolved organic matter on clarification. This should reduce organic contamination of distillate further than that reported by O'Connor and thereby further reduce the ammonia reportedly generated by the hydrolysis of organic matter in the still bottoms.

It should also be obvious that secondary effluent saturated with temporary calcium bicarbonate hardness may be ideal for treatment. If insufficient temporary hardness is available, hot soda-lime processing may be required. Another lime process alternative would be the "cold" lime process to precipitate carbonate and free carbon dioxide, followed by stripping ammonia in a deaerator tower. The incremental cost for the pretreatment system as discussed should be reasonable since the basic operations performed are akin to the requirements for preparing distillation feed and is standard practice in many boiler feedwater preparations. In case the ammonia in the effluent is not stripped when treated, nitrification of the ammonia in the effluent can be included as a requirement of the preceeding biological treatment operation. Some work on the development of this pretreatment technique to the extent necessary to permit its employment with the LTV distillation process is currently being initiated.

Total Treatment Costs

Total cost estimates for renovating municipal secondary effluents into a high grade industrial water supply are as follows:

	Total Cost ¢/1000 gal. 10 - 20 MGD Scale
A. Pre-Treatment	
1. Nitrification	1
2. Hot-Lime-Deaeration stripping and clarification (incremental increase over existing)	2
B. Demineralization	
Un-Optimized (15 MGD) LTV (4)	30 (1961 Cost basis)
C. Post Treat & Disposal	
1. Aeration	1
2. Chlorination	1
3. Brine disposal	1
TOTALS	36¢


MUNICIPAL SECONDARY WASTEWATER EFFLUENT
DISTILLATION BLOWDOWN
CO_2+O_2+?
HEAT EXCHANGER
DEAERATOR TOWER
STEAM FROM DISTILLATION
CONCENTRATE DISPOSAL
TREATED DISTILLATION FEEDWATER
CLARIFY
$CaCO_3$ - ORGANIC SLUDGE

(1) Hot Lime Treatment $Ca(HCO_3)_2 \longrightarrow CO_2 + CaCO_3$

(2) Soda-lime Treatment $CaSO_4 + Na_2CO_3 \longrightarrow Na_2SO_4 + CaCO_3$

(3) Cold Lime Treatment $Ca(HCO_3)_2 + CaO \longrightarrow 2CaCO_3 + H_2O$

Figure 2 - Distillation Feedwater Treatment

Pre- and post-demineralization treatment costs are included based on our best estimate of technical requirements for successful operations. The "hot lime" operation as a distillation pretreatment step assumes a substantial reduction of the organic matter in the feedwater would occur. Nitrification assumes essentially a complete conversion of feed ammonia to a stable nitrate salt.

Conclusion

On the basis of this literature review we believe -- "A New Look at Distillation" (14), is in order in arid regions faced with providing low mineral content waters for industrial uses.

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ANIMAL WASTE RUNOFF - A MAJOR WATER QUALITY CHALLENGE

by

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INTRODUCTION

The feeding of livestock in confinement has created a new major industry. Having become firmly established in the United States by the late 1950's, it continues to rapidly expand. During the emergent stage, designers of cattle feedlots selected sites based primarily on two criteria: drainage and accessibility. The lots were situated on the nearest draw where the rains could scour the waste materials from the lots into nearby gullies and streams. Since, traditionally, animal wastes were considered as "natural" or "background" pollution, control measures were not implemented. In the absence of positive control measures, pollution of the surface waters resulted. Now it is known that animal wastes contaminate water supplies, destroy fish and aquatic life in streams, and generally degrade water quality. More important, it is also known that animal wastes are a controllable major source of water pollution necessitating immediate attention.

However, there are still gaps in our knowledge concerning the most efficient, effective and efficacious means of controlling pollution. This will require that we delineate specific research needed relative to the expected trends of the feedlot industry. Not only must this research answer the most pressing present problems, but also must be simultaneously part of long range plans for developing sufficient technology to control feedlot pollution 5, 10, or 25 years from now. For instance, the interregional adjustments (shifting of location), size, density and other factors are of vital importance in planning research activities. We must, as accurately as possible, project these adjustments.

Prevention and control of animal waste pollution cannot wait while all the data are collected and assembled. To wait for all the answers before taking action would squander time that we do not have. To wait may mean the degradation of many waters beyond the point of recovery with accompanying health hazards of undefined proportions. To quote Robert H. Finch (1), "echoing Aristole, that the ultimate end....is not knowledge, but action. To be half right on time may be more important than to obtain the whole truth too late."

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Increased control is imperative now. To date, the kaleidoscope of alternatives to animal waste pollution control have been honored more fully in principle than in practice. Feedlot runoff could be greatly reduced with a minimum expenditure by utilizing known information. The majority of feedlot operators have not used techniques which minimize the quantity and strength of runoff waste. For instance, research has shown that feedlot runoff may be reduced by adjusting stocking rates and utilizing optimum feedlot surfaces (2,3). What does the future portend? Is it possible that animal wastes and city garbage disposal may both be operated on a public utility basis (4)? Furthermore, is this the mechanism to bring together an entire animal production unit to research methods for the utilization of these products?

A much broader view of waste management may be dictated by socio-economic changes. While the return of the wastes to the land may not be competitive with commercial fertilizers on an immediate crop production basis, it may be highly profitable in terms of public welfare over both the short and long range to use these wastes to reclaim marginal lands. We are losing approximately a million acres of agricultural land each year as a result of urban growth, highway construction, and other natural and man-made incursions into the reserve of productive land (4). It is difficult to equate the true worth to society for the reclamation of lands. Certainly it extends much beyond the yearly crop production.

The residents of the arid and semi-arid regions realize the value of water. Ground water in the semi-arid regions of the Southwest is being mined at an unprecedented rate. For example, in some areas of Arizona the water table is declining as much as 20 feet per year. In many locations the quality of the water deteriorates as the water table lowers. Much of the water now pumped in Central Arizona does not meet minimum agricultural and public health standards (5). Since the agricultural industry consumes the overwhelming portion of the water used, it has the greatest stake in protecting and enhancing water quantity and quality.

ANIMAL PRODUCTION

There are approximately 110 million cattle in the United States. Dairy cattle outnumbered beef cattle in this country until 1942. Since that time the upward trend in beef consumption, the downward trend in milk consumption per capita, and the upward trend in milk yield per cow have combined to shift this cattle population emphasis to almost four to one in favor of beef -- in just 25 years! Approximately one-half of the two billion tons of livestock wastes produced annually in the USA comes from animals in confined feeding. The magnitude of the problem caused by feedlot operations is reflected in the statistics for feeder cattle. Data compiled by Loehr (8) show the waste population equivalent of feeder cattle is greater than the human population in 17 of our 50 states.

The Missouri Basin States of Iowa, Nebraska, Colorado, Kansas, Missouri, North Dakota and South Dakota, feed approximately 50 percent of all slaughter cattle. Iowa leads the Nation in the number of cattle and calves on feed. In 1967, more than 4 million beef cattle were marketed from Iowa feedlots. The majority of the cattle were in small farm feedlots. Only four percent were in feedlots of more than 1,000 head (9). Nebraska ranks second with approximately 35 percent of the fed cattle in feedlots of more than 1,000 head. Third is California, with an average of 1,800 head per feedlot. There was an 87 percent increase in cattle marketings in California between 1957 and 1963 with virtually all the growth occurring in feedlots with 10,000 head or more capacity. Texas, Colorado and Kansas, respectively, rank fourth, fifth and sixth.

The new glamour area for cattlemen is the Central and High Plains areas, including parts of Kansas, Nebraska, Colorado, and the panhandles of Oklahoma and Texas. A recent survey (1968) conducted by the Southwest Public Service Company of Amarillo, Texas, enumerates 274 large commercial feedlots in a 42 county area in Texas, Oklahoma, Kansas, and New Mexico. They have a total one-time capacity of over 1 million head -- 300,000 more than the year before and almost a half-million more than in 1966 (10). The Texas High Plains has become the center of the rapidly expanding cattle industry, experiencing a remarkable 146 percent increase in cattle inventories between 1965 and 1968. Fed cattle inventories for the State increased 66 percent in the same three year period. The exceptional growth of the cattle industry on the High Plains is attributed to an availability of feed, adequate supplies of feeder cattle, an adequate transportation network, rapid growth of irrigation wells, and a favorable climate. Livestock feeders state that cattle performance is better at higher elevations where summer nights are cool and humidity is low (11).

Surveys reported by Colorado, California and USDA during the early growth of the commercial feedlot indicated that optimum feedlot capacity ranged between 10,000 and 20,000 head. Today 30,000 head capacities are routine with 40,000 to 70,000 head lots becoming more prominent in the panhandle area of Texas. Thus, it becomes apparent that growth is still a part of this industry (13). It has been estimated that by the early 1970's, approximately 2,500 large commercial feedlots in the United States will supply nearly 70 percent of all the Nation's finished cattle (10). There does not appear to be an optimum size feedlot. The continuous decline in costs with increases in size seem to justify continued increases in the size of the lots. However, additional studies considering both internal and external costs of operation are needed (12). Studies to date have largely dealt with internal costs -- tax benefits, buying advantages, and other external factors have not been fully evaluated.

COMPOSITION AND QUANTITY OF RUNOFF

The runoff from cattle feedlots can be potent. Miner, et al, (3) reported COD concentrations from 3,000 to 11,000 mg/l, ammonia nitrogen concentrations ranged from 16 to 40 mg/l and suspended solids ranged from 1,500 to 12,000 mg/1. These data provide a basis for an example of the significant difference between population equivalent (PE) values based on runoff and values based on manure production (10,14).

The oft cited PE values based on total animal production have little meaning with regard to water pollution. What we are really concerned with is the amount that enters ground and surface waters. If the objective is to quantify the magnitude of the potential stream pollution, PE values should be based on the strength and volume of wastes which can enter a stream by storm water runoff rather than the total manure production. Dague (14) cites calculations, for a given set of conditions, which demonstrate the BOD actually contributed to the stream is about five percent of the total BOD production of the animal. Other investigators have made estimates of the total annual pollution loads generated by runoff from feedlots. These investigators also demonstrated the quantity and strength of the wastes which enter the streams to be considerably less than that defecated by the animals. Let us now attempt to place this problem into perspective.

Sixty-six thousand feedlots, ranging in capacity up to 100,000 animals blanket 7 of the 10 Missouri Basin States. Animal wastes from the more than 20 million cattle, 16 million swine and 7 million sheep defecate wastes equivalent to 370 million people. Using the previously cited 5 percent figure, then the magnitude of the stream pollution from animal wastes is more than 18 million PE in the Missouri River Basin. The human population of the Missouri Basin Region is 7.9 million. Thus, the calculated stream pollution from animal wastes is more than twice the human population equivalent. We must use caution in predicting and interpreting stream pollution from feedlots. There are many variables which influence the effect of feedlot runoff upon the receiving water course. Among these factors are the climate of the region and the area and nature of the feedlot surface. Also, the antecedent moisture condition of the accumulated waste and the rate at which precipitation occurs are of primary importance in determining the quantity and quality of runoff from a feedlot (2). It has been noted by various investigators (2,10) that the greatest pollutant concentrations are obtained during warm weather, during periods of low rainfall intensity, and when the manure has been dissolved by water soaking.

During warm, dry weather, especially in the semi-arid regions, the most noticeable change in the deposited manure is evaporation of moisture. The wastes become pulverized by the hooves of cattle. If the accumulated waste on the feedlot floor becomes tightly compacted and dry, it provides a relatively imperious barrier to the initial rain, resulting in large quantities of organic runoff. However, if the accumulated manure on the feedlot floor is slightly damp when precipitation begins, it can readily absorb a large quantity of rainfall at a rapid rate, resulting in lesser amounts of runoff during the early stages of the precipitation. The dry, high altitude of the Texas High Plains provides excellent drying conditions for the huge quantities of feedlot wastes. During the summer months, the moisture content of the finely pulverized dehydrated feces and urine solids may go as low as 2 percent (2).

It must be remembered, however, that generalizations concerning feedlot runoff are necessarily lacking in precision. For example, weather conditions alone can be quite important. Data reported by Kansas State University indicated all pollutional parameters greatly exceeded previously measured values during a heavy rainstorm with lot surfaces wet when the rain began. Three inches of precipitation fell during an eight-hour period. Suspended solids were 26,850 mg/l in samples taken 2-1/2 hours after the storm began and 4 hours later were 45,200 mg/l (10).

EFFECT OF ANIMAL WASTE POLLUTION ON WATER QUALITY

Since feedlots have generally been located without regard to the soil inventory and topographic characteristics, surface runoff to streams with subsequent damage from high BOD wastes is common. Infiltration of nitrates from manures to well waters is well documented (6,7). Field disposal of large concentrations of manures can lead to contamination of underground supplies.

Field investigations of fish kills and other water pollution episodes substantiate that the degradation of water quality due to animal wastes is indeed a serious matter. The release or runoff of these wastes to surface streams during periods of rainfall produces "slug" loads of the polluting material which can traverse the receiving stream for many miles, kill all desirable aquatic life in its path, disrupt or prohibit the use of the affected stream for water supply purposes, and generally create public alarm (15). The slug flow and resultant adverse effects of animal wastes can be felt hundreds of miles from their point of entry. Spring rains in Kansas in 1967 washed tons of cattle feedlot wastes into receiving streams resulting in fish kills and ruining the water supply of downstream towns (16). Stream surveys were conducted on the Missouri River in June and July of 1967 during and after a fish kill in the River. The following data were obtained (16):

> Kansas City, Missouri - The dissolved oxygen level dropped to 1.5 mg/l in the river water, and was less than 4 mg/l for 11 days, and did not reach 5 mg/l for 19 days.
>
> St. Joseph, Missouri - At times, the dissolved oxygen level was virtually zero and was less than 4 mg/l for 7 days, and did not reach 5 mg/l for 15 days.
>
> Jefferson City, Missouri - The dissolved oxygen content dropped to 2.1 mg/l and was less than 4 mg/l for 7 days and remained less than 5 mg/l for almost a month.

The flow in the Missouri River at all three stations ranged from approximately 80,000 to 260,000 cfs with an average of 180,000 cfs at Kansas City. Based on the above flows and dissolved oxygen deficiencies, the oxygen demand was equivalent to the waste BOD from 80 to 120 million people. Approximately 3 million population equivalent is the maximum that can be accounted for from municipal and industrial sources (16). Animal wastes are one of the prime suspects for the large unaccountable pollution load.

Surface water supplies in Kansas have been seriously disrupted by feedlot runoff pollution. One such incident is described by an Official (17) of the Kansas State Department of Health:

> "In 1967 one small Kansas community using surface water as a supply source was forced for a period of two weeks to treat water with the following characteristics: ammonia content up to 20 mg/l; BOD_5 up to 75 mg/l; dissolved oxygen 0.0 mg/l; total coliform count 4 million; fecal coliform count 2 million, and total fecal streptococcus count at 5 million per 100 m/l sample. Additionally the water was heavily loaded with pungent and difficult-to-describe organic materials which produced a finished water product highly offensive to the senses of taste and smell. The city was forced to use activated carbon and increase chlorination by a factor of 10 in order to 'not-too-successfully' continue operation of the water treatment plant."

There is additional evidence that animal wastes are a major source of water quality degradation. During the past year, an estimated 12 million fish were killed by pollution in our waters. This terrible toll reflects only the actual kills discovered and reported. Many more thousands of dead fish go unnoticed or unreported each year (18). Thirty-six fish kills in Kansas streams were investigated by the Kansas State Department of Health and the Forestry, Fish and Game Commission during 1967-1968. Twenty-two of these were attributed to runoff from commercial feedlots (19). Spring rains in Kansas in 1967 washed tons of cattle feedlot wastes into the receiving streams killing an estimated 500,000 fish. This is not to say that fish kills are unique to Kansas, but rather suggests a greater awareness by Kansas officials of the pollution caused by animal wastes. Recently, in Kansas, a large dairy herd was decimated after drinking from a well polluted by the runoff from beef cattle waste. This dramatically illustrates the serious contamination that can be caused by uncontrolled animal wastes (8).

Animal waste pollution is not restricted to the Midwest; it is a national problem. In early 1966, the Interstate Commission on the Potomac River Basin reported (20):

> "Every time it rains ... enormous amounts of animal wastes are washed from farmyards into the river, rendering it unsafe for swimming .. although only a quarter-of-a-million people live in the river basin

> above Great Falls, it has been estimated that the number of farmyard animals -- cows, sheep, pigs, chickens, turkeys -- is the equivalent of a human population of 3.5 million. While most of the human population is served by some sort of sewage treatment plant, there is no comparable treatment for the animal wastes."

Still another affected area is in the great Southwest. For example, the residents of Milford, Texas, have brought numerous damage suits involving pollution against a large feedlot located a mile from the community (21). The rapid growth of the cattle feeding industry in the semi-arid lands of the Southern and High Plains areas has resulted in the concurrent development of major water pollution problems.

Numbers of cattle on feed and feedlots with a capacity of 1,000 head or more increased five-fold in the Southern Plains since the mid 1950's (2). The problem starts with the cumulative build-up of large quantities of organic waste on cattle feedlots subjected to sporadic and intense rainfall. Evaporation rates are high in summer and the limited rainfall (15-20 inches annually) comes in sporadic bursts over short time periods and unless controlled, this runoff will enter the water courses.

One of the most pressing needs in water pollution control is to slow the eutrophication rate of lakes (aging process) which is accelerated by overenrichment from agricultural, industrial and municipal wastes. Lake Erie is the most dramatic -- and potentially tragic -- example of oxygen depletion in the water caused by nuisance aquatic plants filling the lake. Many other lakes -- large and small -- are in the same desperate condition but have not achieved the national recognition afforded Lake Erie. Although other nutrient sources such as municipal sewage and industrial discharges are big contributors to eutrophication, the vast amount of manure being produced in this country is one of the major causes of the killing of a lake or river by accelerated eutrophication (22). Nitrates and phosphates cause eutrophication, and manure contains both of these plant nutrients. They can be carried by runoff into the streams or percolate through soils to enter the waterways.

In Minnesota, attention to the problem of eutrophication was brought forth by the study on the Big Stone Lake where preliminary investigations indicate a large amount of the nutrients entering the lake is from cattle feedlots. The Minnesota Pollution Control Agency stated (23) "there are places in the country where three or four times as much raw sewage enters our streams from animals as from human beings." Studies on Lake Mendota near Madison, Wisconsin, points the accusing finger at manure carried by spring runoff into the lake as the source of unwanted nutrient enrichment and growth of water plants. Limnologists see eutrophication taking place in other beautiful lakes in Minnesota and other states (24).

EFFECT OF ANIMAL WASTES ON GROUND WATER

In a statewide survey the University of Missouri analyzed more than 6,000 water samples in Missouri. Forty-two percent of the water samples contained more than 5 parts per million as nitrogen nitrate (25). In some counties in Northwest Missouri, over 50 percent of the wells sampled contained sufficient nitrogen to be of concern in livestock production. Data indicated animal manure to be one of the major sources of nitrate in water supplies. There was a definite statistical relationship between livestock numbers and shallow wells containing nitrate.

Agriculture's effect on nitrate pollution of ground water was also investigated in the South Platte River Valley of Colorado. Most of the 621,000 cattle in Colorado feedlots (February 1, 1967) were located in this valley. Data showed that nitrate under feedlots is moving through the soil and into the ground water supply. Since the feedlots are usually located near the homestead, they may have a pronounced effect on the water quality from domestic wells. The findings that water under feedlots frequently contained ammonium and organic carbon cause further concern about the effect of feedlots on underground water supplies (7).

ACCOMPLISHMENTS: KEYS TO THE PROBLEM

The culmination of comprehensive Federal water pollution control legislation came with the enactment of the Federal Water Pollution Control Act, Public Law 660, in 1956. This law is the basis for the Federal role and responsibility in water pollution control and stresses the recognition of the State responsibility in water pollution control. The amendments represented by the Water Quality Act of 1965 and the Clean Water Restoration Act of 1966 were extensive and far-reaching.

The official state enforcement agencies are assuming their responsibility in animal waste control. For example, eight of the 10 Missouri River Basin States have enacted or are now in the process of enacting, feedlot regulations. Regulations are, in effect, the blueprints for the animal waste control program. They act as a guide to planning, construction and enforcement. Regulations are needed to ensure the feedlot operator that the measures he is taking will guarantee a reasonable tenure of operation. It is necessary that the operator know the controls being installed are adequate, and secondly, that frequent changes will not be sought by the official agency. Uniformity which concurrently allows for flexibility must be built into the regulations. Different requirements may constitute an economic barrier and are especially confusing to operators conducting business in two or more states.

The existing legislation pertaining to feedlot pollution control should be thoroughly evaluated. Many of the basic concepts contained in the regulations are sound. However, more attention should be directed to management practices which would prevent the wastes from entering surface or ground waters. For instance, the percent removal concept of municipal sewage treatment is not applicable to the control of feedlot pollution. Cattle feedlot runoff is a highly concentrated organic waste. The strength may equal that of normal domestic sewage or may be 10, 100, 1,000 or more times greater. Feedlot runoff may still contain, after treatment, as high pollutional parameters as domestic sewage, before treatment, if percent removal is the only criterion used for treatment. Therefore, a "residual" concept of waste treatment is proposed. That is, acceptable treatment is that which reduces the pollution to a prescribed level or residual which would assure adequate treatment.

Our laws must give due consideration to the location of feedlots. Feedlots have generally been located without regard to the soil inventory and associated topographical characteristics. It may be not only desirable, but also necessary, to employ zoning regulations to prevent the encroachment of the animal population into urban areas, as well as to prevent the encroachment of the human population into the feedlot areas. Hawaii and California have shown the way with the passage of land conservation acts. Basically, their legislation prevents encroachment of urban development into agricultural areas and also provides a more favorable tax assessment for agricultural lands.

Regulations should also provide for a continuing, comprehensive animal inventory, state by state, drainage basin by drainage basin, which would provide definitive data on the character and composition of agricultural effluents, points of discharge and other pertinent information. Just as we census the human population, we must also keep up-to-date inventories of animal populations.

Leadership in animal waste control is not limited to the official agencies. Research has been underway in the state agricultural experiment stations regarding the characterization, handling, and utilization of animal manures since the turn of the century. The U. S. Department of Agriculture and many other Federal and State agencies are conducting studies related to agricultural pollution.

CONCLUSION

An enlightened public has shown in all fields of environmental protection, including water pollution control, that it is willing to pay, in dollars, the added costs of maintaining a high quality environment, rather than risk its own destruction. Enlightened leadership will continue to create its own consensus. This paper has presented an overview of the causes and effects of animal waste pollution on water quality. The extent of the problem as well as the effects on surface and ground waters are illustrated with research data. The present status of legislation in regulatory control of pollution is discussed. Measures to strengthen present regulations are proposed.

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